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COMPARISON OF FIELD AND LABORATORY BIOACCUMULATION OF ORGANIC AND INORGANIC CONTAMINANTS FROM BLACK ROCK HARBOR DREDGED MATERIAL

by

James L. Lake, Walter Galloway, Gerald Hoffman

Environmental Research Laboratory US Environmental Protection Agency Narragansett, Rhode Island 02882

and

William Nelson, K. John Scott

Science Applications International Corporation Narragansett, Rhode Island 02882

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19 ABSTRACT (Continue on reverse if necessary and identify by block number) The utility of laboratory tests for predicting bioaccumulation of contaminants in the field was evaluated by comparing the identities, relative abundances, and quantities of organic and inorganic contaminants accumulated by organisms exposed to dredged material in both laboratory and field studies. The organisms used were <i>Mytilus edulis</i> (a filter-feeding bivalve) and <i>Nephtys incisa</i> (a benthic polychaete). These organisms were exposed in the laboratory and in the field to a contaminated dredged material from Black Rock Harbor (BRH), Connecticut. In the laboratory, test organisms were exposed to BRH sediment or mixtures of BRH and a reference sediment (REF). <i>Mytilus edulis</i> were exposed to 0-, 10-, 30-, 50-, and 100-percent BRH material at a total suspended solids concentration of 10 mg/l in 14- or 28-day laboratory tests. In the field, <i>M. edulis</i> were deployed in cages for 1 month or (Continued)					
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longer near the disposal mound and at a reference site before, during (where possible), and subsequent to the disposal of 55,000 cu m of BRH material at the study site. Similar pattern (relative abundances of constituents within a sample) and concentration changes for polychlorinated biphenyls (PCBs), and concentration changes for some polycyclic aromatic hydrocarbons (PAHs) and the pesticide ethylan, were observed in residues from *M. edulis* exposed to BRH material in the laboratory or from field exposure to BRH material at stations near the disposal site. The similarity of these changes indicated a relationship between the laboratory and field bioaccumulations for *M. edulis*. For the patterns of PAHs and for metals in *M. edulis*, no relationships between laboratory and field bioaccumulations were found.

Nephtys incisa were exposed to 0-, 10-, and 30-percent BRH in a bedded exposure test for 55 days, or to 0-, 50-, and 100-percent BRH in a suspended exposure test at 200 mg/l for 42 days. *Nephtys incisa* were collected at the field stations before, during, and subsequent to the disposal of BRH material. Relationships were found in the patterns and concentrations of PCBs and PAHs in residues in *N. incisa* exposed in the laboratory and in the field. No relationships between laboratory and field exposures could be found for metals accumulated in *N. incisa*. The laboratory-to-field relationships found in this study demonstrate that properly designed laboratory exposure tests have utility for predicting the identities and patterns of PCB and PAH contaminants accumulated in some field-exposed organisms.

Both organisms had positive and negative attributes for these exposure studies. *Mytilus edulis* appeared to reach steady-state in laboratory exposure studies. However, the determination of field exposure concentrations was precluded due to limitations on obtaining an integrated water sample during the exposure period in the field. *Nephtys incisa* did not appear to reach steady-state in laboratory studies and although field exposure data (sediment concentrations) were obtained, the exposure zone for these organisms could not be determined. Estimates of field exposures were made using laboratory-derived exposure-residue relationships and residues from field-exposed organisms. These field exposure estimates were compared with those estimated using exposure data from the field. A comparison of these estimates showed the same general trends in the exposure-residue relationships from the laboratory and the field and further supports the laboratory-predictive approach.

In general PCB contaminants appeared to be the most useful compounds in these studies. For PCBs the pattern changes observed in residues following exposure were consistent and clearly showed exposure to BRH material. PAHs showed less consistent pattern changes possibly due to the metabolism of these compounds by organisms. Metals were the least useful contaminants for establishing laboratory-to-field relationships.

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SUBJECT: Transmittal of Field Verification Program Technical Report Entitled "Comparison of Field and Laboratory Bioaccumulation of Organic and Inorganic Contaminants from Black Rock Harbor Dredged Material"

TO: All Report Recipients

1. This is one in a series of scientific reports documenting the findings of studies conducted under the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives (referred to as the Field Verification Program or FVP). This program is a comprehensive evaluation of environmental effects of dredged material disposal under conditions of upland and aquatic disposal and wetland creation.
2. The FVP originated out of the mutual need of both the Corps of Engineers (Corps) and the Environmental Protection Agency (EPA) to continually improve the technical basis for carrying out their shared regulatory missions. The program is an expansion of studies proposed by EPA to the US Army Engineer Division, New England (NED), in support of its regulatory and dredging missions related to dredged material disposal into Long Island Sound. Discussions among the Corps' Waterways Experiment Station (WES), NED, and the EPA Environmental Research Laboratory (ERLN) in Narragansett, RI, made it clear that a dredging project at Black Rock Harbor in Bridgeport, CT, presented a unique opportunity for simultaneous evaluation of aquatic disposal, upland disposal, and wetland creation using the same dredged material. Evaluations were to be based on technology existing within the two agencies or developed during the six-year life of the program.
3. The program is generic in nature and will provide techniques and interpretive approaches applicable to evaluation of many dredging and disposal operations. Consequently, while the studies will provide detailed site-specific information on disposal of material dredged from Black Rock Harbor, they will also have great national significance for the Corps and EPA.
4. The FVP is designed to meet both Agencies' needs to document the effects of disposal under various conditions, provide verification of the predictive accuracy of evaluative techniques now in use, and provide a basis for determining the degree to which biological response is correlated with bioaccumulation of key contaminants in the species under study. The latter is an important aid in interpreting potential biological consequences of bioaccumulation. The program also meets EPA mission needs by providing an opportunity to document the application of the generic predictive hazard-assessment research strategy applicable to all wastes disposed in the aquatic environment. Therefore, the ERLN initiated exposure-assessment studies at the aquatic disposal site. The Corps-sponsored studies on environmental consequences of aquatic disposal will provide the effects assessment necessary to complement the EPA-sponsored exposure assessment, thereby allowing ERLN to develop and apply a hazard-assessment strategy. While not part of the Corps-funded FVP, the EPA exposure-assessment studies will complement the Corps' work, and together the Corps and the EPA studies will satisfy the needs of both agencies.

SUBJECT: Transmittal of Field Verification Program Technical Report Entitled "Comparison of Field and Laboratory Bioaccumulation of Organic and Inorganic Contaminants from Black Rock Harbor Dredged Material"

5. In recognition of the potential national significance, the Office, Chief of Engineers, approved and funded the studies in January 1982. The work is managed through the Environmental Laboratory's Environmental Effects of Dredging Programs at WES. Studies of the effects of upland disposal and wetland creation were conducted by WES, and studies of aquatic disposal were carried out by the ERLN, applying techniques worked out at the laboratory for evaluating sublethal effects of contaminants on aquatic organisms. These studies were funded by the Corps while salary, support facilities, etc., were provided by EPA. The EPA funding to support the exposure-assessment studies followed in 1983; the exposure-assessment studies are managed and conducted by ERLN.

6. The Corps and EPA are pleased at the opportunity to conduct cooperative research and believe that the value in practical implementation and improvement of environmental regulations of dredged material disposal will be considerable. The studies conducted under this program are scientific in nature and are published in the scientific literature as appropriate and in a series of Corps technical reports. The EPA will publish findings of the exposure-assessment studies in the scientific literature and in EPA report series. The FVP will provide the scientific basis upon which regulatory recommendations will be made and upon which changes in regulatory implementation, and perhaps regulations themselves, will be based. However, the documents produced by the program do not in themselves constitute regulatory guidance from either agency. Regulatory guidance will be provided under separate authority after appropriate technical and administrative assessment of the overall findings of the entire program.


 James Choromokos, Jr., Ph.D., P.E.
 Director, Research and Development
 U. S. Army Corps of Engineers


 Bernard D. Goldstein, M.D.
 Assistant Administrator for
 Research and Development
 U. S. Environmental Protection
 Agency



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PREFACE

This report describes work performed by the US Environmental Protection Agency (USEPA), Environmental Research Laboratory, Narragansett, R. I. (ERLN), as part of the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program (Field Verification Program (FVP)). The FVP was sponsored by the Office, Chief of Engineers, US Army (OCE) and was assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program was to field verify existing predictive techniques for evaluating the environmental consequences of dredged material disposal under aquatic, intertidal, and upland conditions. The aquatic portion of the FVP was conducted by ERLN, with the wetland and upland portion being conducted by WES.

The principal investigators for this aquatic study and authors of this report were Dr. James L. Lake, Mr. Walter Galloway, and Dr. Gerald Hoffman, ERLN, and Mr. William Nelson and Dr. K. John Scott, Science Applications International Corporation (SAIC). Diving support for the field portion of the study was provided by Messrs. Bruce Reynolds and Norman Rubinstein, ERLN, and Greg Tracey, SAIC.

Analytical chemistry support was provided by Mr. Richard Lapan, Mr. Curtis Norwood, and Mr. Frank Osterman, ERLN; Mr. Richard McKinney, Mr. Warren Boothman, Ms. Adria Elskus, Ms. Eileen McFadden, Mr. Lawrence LeBlanc, Mr. Robert Bowen, and Ms. Sharon Pavignano, SAIC; and Ms. Kathleen Schweitzer, University of Rhode Island.

Ms. Joan E. Seites, Ms. Barbara S. Gardiner, and Ms. Colette J. Brown, Computer Science Corporation (CSC), provided word processing support in the preparation of this report. Critical reviews of this report were completed by Drs. Peter F. Rogerson, Henry Lee, and Robert Randall, ERLN. Technical reviews by WES personnel were also provided.

The EPA Technical Director for the FVP was Dr. John H. Gentile, and the Technical Coordinators were Dr. Gerald Pesch and Mr. Walter Galloway. The OCE Technical Monitors were Drs. John Hall, Robert J. Pierce, and William L. Klesch.

The study was conducted under the direct WES management of Drs. Thomas M. Dillon and Richard Peddicord and under the general management of Dr. C. Richard Lee, Chief, Contaminant Mobility and Criteria Group;

Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, Environmental Laboratory. The FVP Coordinator was Mr. Robert L. Lazor, and the EEDP Managers were Mr. Charles C. Calhoun, Jr., and Dr. Robert M. Engler. Dr. Thomas D. Wright was the WES Technical Coordinator for the FVP reports. This report was edited by Ms. Jamie W. Leach of the WES Information Technology Laboratory.

COL Dwayne G. Lee, CE, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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COMPARISON OF FIELD AND LABORATORY BIOACCUMULATION OF
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PART I: INTRODUCTION

Background

1. The Marine Protection, Research, and Sanctuaries Act (Public Law 92-532) was passed by Congress in 1972. This law states that it is the policy of the United States to regulate disposal of all types of materials into ocean waters and to prevent or strictly limit disposal of any material that would adversely affect human health, welfare, the marine environment, or ecological systems. The implementation of this law, through the issuance of permits as defined in the final regulations and criteria, is shared jointly by the US Environmental Protection Agency (USEPA) and the US Army Corps of Engineers (CE).

2. In 1977, the CE and the USEPA prepared technical guidance for the implementation of the final ocean dumping regulations in the form of a manual entitled "Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters" (USEPA/CE 1977). This manual specified which test procedures were to be followed in collecting information to be used in making a disposal decision. Among the procedures were those for: (a) chemically characterizing the proposed dredged material; (b) determining the acute toxicity of liquid, suspended particulate, and solid phases; (c) estimating the potential contaminant bioaccumulation; and (d) describing the initial mixing during disposal. These methods have been used for determining the suitability of dredged material for open-water disposal. The procedures in this manual represented the technical state of the art at that time and were never intended to be inflexible methodologies. The recommended test methods were chosen to provide technical information consistent with the criteria specified in the regulations. However, use of the manual in the permit process has identified conceptual and technical limitations with the recommended test methods (Gentile and Scott 1986).

3. To meet this critical need, the Interagency Field Verification of

Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program, or the Field Verification Program (FVP), was authorized in 1982. This 6-year program was sponsored by the Office, Chief of Engineers, and was assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program was to field verify existing test methodologies for predicting the environmental consequences of dredged material disposal under aquatic, wetland, and upland conditions. The aquatic portion of the FVP was conducted by the USEPA Environmental Research Laboratory, Narragansett, R. I. (ERLN). The wetland and upland portions, being conducted by WES, are reported in separate documentation.

4. ERLN was responsible for conducting research on the aquatic portion for disposal of dredged material. There were three research objectives for this portion of the program. The first was to demonstrate the applicability of existing test methods for detecting and measuring the effects of dredged material, and to determine the degree of variability and reproducibility inherent in the testing procedure. This phase of the program (Laboratory Documentation) is complete, and the results have been published in a series of technical reports. This information provides insight into how the various methods function, their sources of variability, their respective and relative sensitivities to the specific dredged material being tested, and the degree of confidence that can be placed on the data derived from the application of the methods.

5. The second objective was to field verify the laboratory responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that results derived from laboratory test methods are directly applicable in the field. While this assumption is intuitive, there are no supporting data from studies on complex wastes in the marine environment. The study reported herein offers a unique opportunity to test this basic assumption. The third objective was to determine the degree of correlation of tissue residues resulting from bioaccumulation of dredged material contaminants with biological responses from laboratory and field exposure to dredged material. However, because this study was not designed to address cause-effect relationships and the sediment contained multiple contaminants, any such assumptions are precluded.

Project Description

6. The aquatic disposal portion of the FVP was a site- and waste-specific case study that applied the concepts and principles of risk assessment. The disposal site for the FVP is a historical site known as the Central Long Island Sound (CLIS) disposal site (1.8 by 3.7 km) located approximately 15 km southeast of New Haven, Conn. (Figure 1). The sedimentology at the

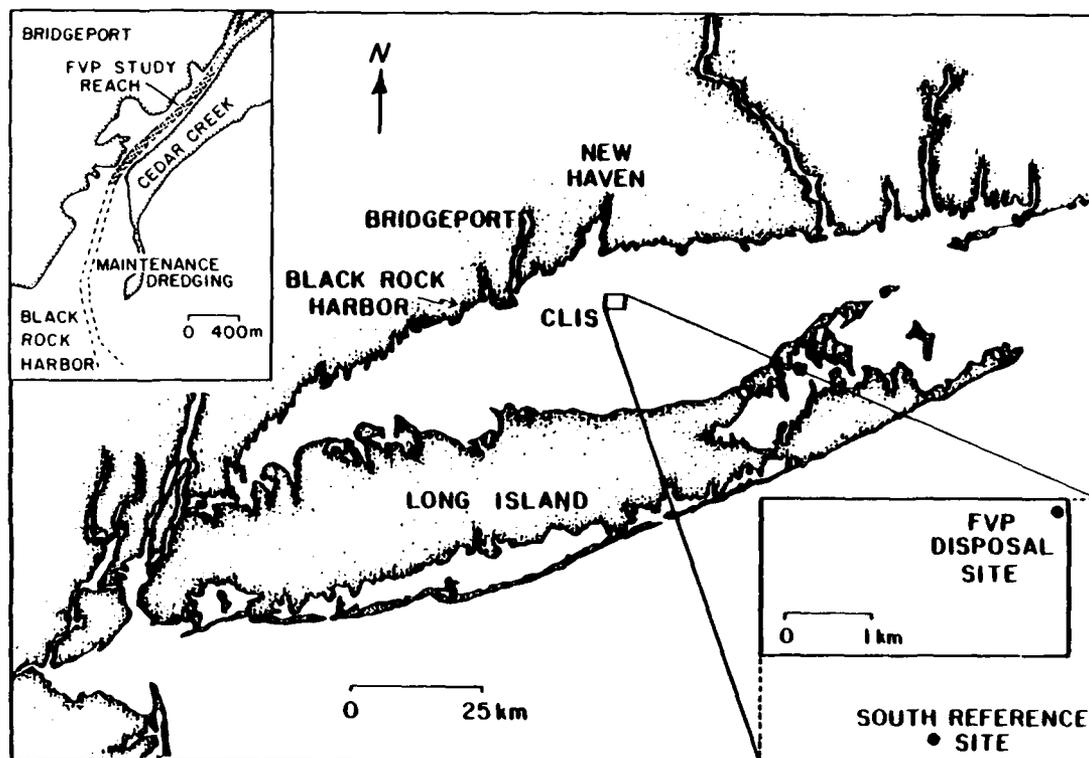


Figure 1. Central Long Island Sound disposal site and Black Rock Harbor dredge site

disposal and reference sites is primarily silt-clay, with a mean grain size of 0.013 mm. Thermal stratification occurs from April to September, and during this period bottom salinity is slightly higher than that of the surface. Tidal currents typically dominate the near-bottom water in an east-west direction. The net bottom drift is to the northwest at 0.5 cm/sec. Suspended sediment concentrations average 10 mg/l, with storm-induced values to 30 mg/l. The baseline community data revealed a homogeneous, mature infaunal community dominated by the polychaete *Nephtys incisa* and the bivalve molluscs *Nucula proxima* and *Yoldia limatula*.

7. The FVP disposal site was selected within the CLIS so as to minimize contamination from other sources, including relic disposal operations or ongoing disposal activities occurring during the study period, and was an attempt to ensure a point source of contamination. The uniformity of physical, chemical, and biological properties of the disposal site prior to disposal allowed detection of changes in these properties due to the disposal of the dredged material. Finally, the stations used to study the biological effects in this study were selected along the primary axis of current flow to represent a gradient of potential exposure for the biota (Figure 2).

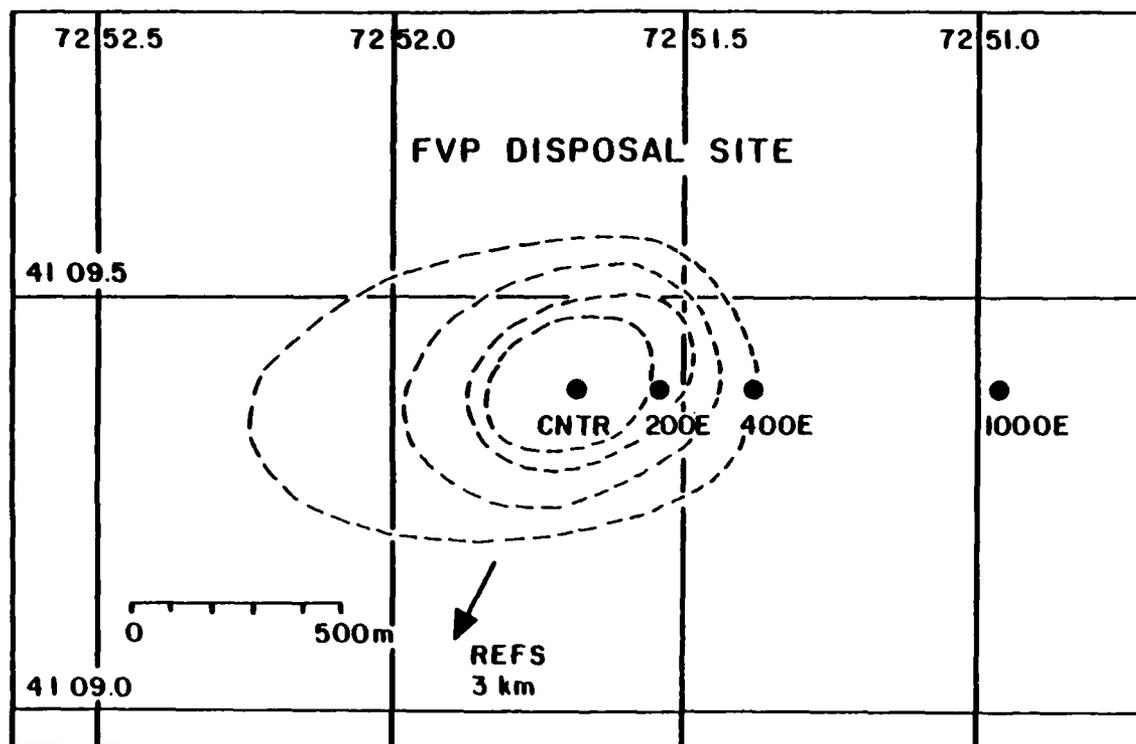


Figure 2. FVP sampling stations

8. The spatial scale of this study was near-field and limited to the immediate vicinity of the disposal site. The temporal scale for the study was 4 years, which included a year of predisposal data collection to define seasonal patterns in the physical, chemical, and biological variables and 3 years of postdisposal data collection to address the objectives of the program and to evaluate the long-term impacts of the disposal operation on the surrounding benthic communities.

9. The dredging site was Black Rock Harbor (BRH), located in

Bridgeport, Conn., where maintenance dredging provided a channel 46 m wide and 5.2 m deep at mean low water (Figure 1). Approximately 55,000 m³ of material was dredged during April and May 1983 and disposed in 20 m of water in the northeastern corner of the CLIS disposal site.

10. The dredged material from BRH contained substantial concentrations of both organic and inorganic contaminants (Rogerson, Schimmel, and Hoffman 1985). Polychlorinated biphenyls (PCBs) were present in the dredged material at a concentration of 6,400 ng/g, and polynuclear aromatic hydrocarbons (PAHs) with molecular weights between 166 and 302 were present at concentrations ranging from 1,000 to 12,000 ng/g, respectively. Alkyl homologs of the PAHs were also present in the dredged material at concentrations between 1,000 and 13,000 ng/g. Inorganic contaminants of toxicological importance present in the dredged material included copper (2,900 µg/g), chromium (1,480 µg/g), zinc (1,200 µg/g), lead (380 µg/g), nickel (140 µg/g), cadmium (24 µg/g), and mercury (1.7 µg/g).

Project Scope

11. The FVP was unique among marine research studies for several reasons. The program objectives were directly focused on addressing specific limitations in the methodologies and interpretive framework of the current regulatory process. Among the program strengths were the following: (a) a suite of biological endpoints using the same material was developed and evaluated; (b) the biological tests represented different levels of biological organization; (c) the tests were conducted under both laboratory and field exposure conditions; (d) the tissue residues were examined concurrently with measurements of biological effects; (e) the duration of the study was adequate to evaluate the use of community responses as a benchmark against which other biological responses could be compared; and (f) the project was a site- and waste-specific case study for the application and evaluation of the components of a risk assessment, including the development of methodologies for predicting and measuring field exposures in the water column and benthic compartments. Limitations of this study were that: (a) only one dredged material was evaluated, which constrained certain types of comparisons, and (b) the size of the study put limits on the extent to which any given objective could be examined. The latter is particularly important because the

laboratory-field comparisons and the risk assessment process both require accurate predictions of environmental exposures.

Laboratory-to-Field Comparisons

12. The field verification of laboratory test methods was designed to compare the exposure-response relationships measured in both the laboratory and the field. Exposure for the purposes of this discussion includes the total dredged material with all of its contaminants. Specific contaminants are used as "tracers" to verify the exposure environment, which is described in terms of BRH dredged material, and to illustrate exposure-response relationships between the laboratory and the field. The specific contaminants are a subset of a comprehensive suite of chemicals analyzed in this study and were selected based upon their environmental chemistry and statistical representativeness. The use of specific contaminants in no way implies a cause-and-effect relationship between contaminant and response.

13. Exposure in open marine systems is characterized by highly dynamic temporal and spatial conditions and cannot be completely replicated in laboratory systems. Consequently, the approach chosen for this program was to develop laboratory exposure-response data using only general field exposure information.

Bioaccumulation

14. One of the principal concerns associated with the ocean disposal of dredged material is the potential for bioaccumulation of organic and inorganic contaminants. The Marine Protection, Research, and Sanctuaries Act and the Clean Water Act require that regulators evaluate the potential environmental effects (including bioaccumulation) of proposed dredged disposal.

15. Bioconcentration as generally defined and used in this report is the uptake of dissolved compounds across gill surfaces or through the integument; bioaccumulation as used here includes the process of bioconcentration in addition to the accumulation of contaminants through food and from direct transfer from particulate material.

16. Studies examining the extent of bioconcentration (with exposure from the dissolved phase only) of organic compounds by marine and aquatic organisms

found it was inversely related to the aqueous solubility S of the compound and directly related to the octanol water partition coefficient Kow (Bysshe 1982). Predictive correlations between the bioconcentration factor (concentration of the contaminant in the organism at steady-state (wet weight)/ concentration of the contaminant in the dissolved phase) and Kow or S have been empirically developed for many compound classes. These correlations are useful only for estimating the concentrations of some organic compounds in organisms exposed to dissolved contaminants. Therefore, these relationships are inadequate for predicting bioaccumulation where exposure may be to contaminants in bedded sediments or suspended particulates, where routes of exposure are complex, and for polar organics and most metals. Further, in the natural environment where a variety of contaminants are likely, both synergistic and antagonistic effects may render these relationships inadequate for predicting bioaccumulation.

17. In an attempt to predict bioaccumulation of contaminants associated with dredged material, the USEPA and the CE included bioaccumulation testing as part of its predisposal evaluation of dredged material (USEPA/CE 1977). These tests exposed an infaunal organism, an epifaunal organism, and a fish to the dredged material for 10 days in static tests. Any statistically significant concentration of PCBs, chlorinated pesticides, and/or metals in exposed organisms above those found in organisms from the reference sediment was considered in the disposal evaluation. These tests were an important first step because they recognized the need for estimates of bioaccumulation from wastes with sediments containing numerous contaminants. Further, these tests introduced a quantitatively established decision point (statistically significant elevation of contaminant residues) for bioaccumulation, which was considered along with other site-specific data in the decision-making process. Unfortunately, these 10-day tests may have been too short for contaminants to reach steady-state concentrations in organisms. The test results were therefore difficult to use effectively in disposal decisions.

18. To have maximum utility for predicting field bioaccumulations routine laboratory bioaccumulation tests must: (a) run in relatively short time periods, (b) be repeatable, (c) have sufficient similarities in exposure conditions and organism types between the laboratory tests and the proposed field disposal site to allow applicability of the test results to the field site, and (d) produce information that can form the basis for a regulatory decision.

19. Unfortunately, the requirements for good bioaccumulation tests are not easily satisfied when dealing with the multitude of variables that may impact the results of bioaccumulation tests (i.e., sediment type, contaminant type, contaminant release rates from sediments, uptake rates and efficiencies for organisms, organism depuration rates and metabolic processes, etc.).

20. Routine bioaccumulation tests should run for short time periods (≤ 30 days) to facilitate disposal decisions.

21. The results of tests must be repeatable. While this is an obvious requirement for the test, numerous factors can contribute to a lack of precision in these tests. The processes of extraction, analysis, and quantification of contaminants at trace levels in organisms, sediments, and water introduce variability into test results. Further, some organisms that have been used in bioaccumulation tests such as *Mercenaria mercenaria* are able to avoid exposure to contaminants, and thereby uptake, by closing. Finally, the health of organisms may be impacted by exposure to dredged material; these changes may affect contaminant accumulation and contribute to variability in the results.

22. One way to decrease variability in test results is to standardize exposure conditions and organisms used in the laboratory tests. However, without adequate links between the laboratory tests and the field, laboratory test results may not be applicable to the selected field situation. For example, the accumulation of dissolved organic contaminants by fish held in constant conditions in the laboratory is not useful for estimating the accumulation of metals by infaunal polychaetes exposed to dredged material in the field. Obviously, some simulation of field conditions in the laboratory is needed before useful predictive results can be obtained from tests.

23. A predictive laboratory bioaccumulation test will not be developed in one or two simple studies. With the FVP, however, an opportunity was presented to begin the process of bioaccumulation test development for dredged material by both developing and testing laboratory bioaccumulation tests and then comparing results with those found in the field. Previous studies in the FVP developed exposure methods and examined the sensitivity of laboratory bioaccumulation tests by examining the accumulation of organic and inorganic contaminants by a marine bivalve and an infaunal polychaete (Lake, Hoffman, and Schimmel 1985). Other FVP studies have documented the impacts of exposure of organisms to BRH material. The present study used the information from the

previous work to modify laboratory exposure conditions and methods to ensure that organisms were exposed to dredged material contaminants, and that the effect of exposure did not adversely impact the bioaccumulation of contaminants.

24. The major effort in the present study is to compare bioaccumulation of contaminants in the laboratory studies with bioaccumulation found in field organisms. The approach in this study is to examine the identities of contaminants and their distributions in the residues from the laboratory studies and the field exposures; and, where possible, to establish links between residue concentration and exposure from both locations. This approach allows an evaluation of the success of the laboratory tests for predicting field bioaccumulations. The contaminant distributions in residues accumulated in the laboratory and field were compared to determine if: (a) the same contaminants were accumulated, and (b) the relative proportions of the individual compounds or elements in these residues were similar in both exposures. The success of these qualitative comparisons was evaluated to determine if the degree of laboratory simulation of the field conditions was adequate. If different contaminants were accumulated or radically different contaminant patterns were found in the residues of the laboratory and field organisms, then laboratory simulations (organisms and exposure conditions) of field exposure conditions were not sufficiently close for any further laboratory-to-field comparisons to be made. When contaminant type and distributions were similar in residues from laboratory and field organisms, relationships between exposure concentrations and residues were developed from the laboratory exposures. These relationships combined with the field residue values were used to estimate field exposure concentrations. Finally, the link between laboratory and field exposure concentrations was checked by comparing estimated field exposure concentrations with available measured field exposure data.

PART II: MATERIALS AND METHODS

Laboratory Methods

Sediment collection

25. Two sediment types were used to conduct laboratory tests for the field verification studies. The reference (REF) sediment was collected from the South Reference site in Long Island Sound (40°7.95' N and 72°52.7' W) by Smith-MacIntyre grab (0.1 m²), press sieved through a 2-mm sieve, and stored at 4° C until used. Prior to dredging, contaminated sediment was collected from Black Rock Harbor (41°9' N and 73°13' W) with a gravity box corer (0.1 m²) to a depth of 1.21 m, thoroughly mixed, press sieved through a 2-mm sieve, and refrigerated (4° C) in barrels until used. Details of sediment collection and storage procedures may be found in Rogerson, Schimmel, and Hoffman (1985). In all experiments, sediments were allowed to reach test temperature and were mixed prior to use.

Organisms collection and holding

26. Mytilus edulis. Two separate experiments were completed using oxidized REF and BRH sediments. *Mytilus edulis* were collected from the Narragansett Bay reference population (71°24.0' W by 41°29.4' N) with a scallop dredge from a depth of 10 m. Collection information for each experiment is listed in Table 1. The animals were sorted to obtain a size range of 50- to 55-mm shell length and acclimated in flowing unfiltered Narragansett Bay seawater at a rate of 1° C per day to 15° C.

27. Nephtys incisa. A suspended exposure and a separate bedded exposure bioaccumulation test were conducted with *N. incisa*. *Nephtys incisa* for laboratory studies were collected with a Smith-MacIntyre grab sampler

Table 1
Collection Information for *M. edulis* Used
in the Laboratory Experiments

<u>Experiment</u>	<u>Collection Date</u>	<u>Experiment Start Date</u>	<u>Temperature °C</u>	<u>Salinity g/kg</u>
1	17 Jan 85	05 Feb 85	2.0	30.0
2	22 Feb 85	12 Mar 85	5.0	30.0

(0.1 m²) at the South Reference site (Figure 1). Collection information for each experiment is listed in Table 2. The sediment containing the *N. incisa* was brought to the laboratory where it was sieved, and the *N. incisa* were picked and sorted by size. Tests were conducted with individuals 3 to 4 cm in length. These individuals were placed in REF sediment, in flowing seawater. For the bedded exposures the ambient temperature increased from 10° C to 12° C during the holding period, and no food was provided. For the suspended exposures, organisms were acclimated at a rate of 1° C per day to 20° C, and they were fed powdered prawn flakes, ad libitum during this period.

Table 2
Collection Information for *N. incisa* Used
in the Laboratory Experiments

<u>Experiment</u>	<u>Duration</u> <u>days</u>	<u>Collection</u> <u>Date</u>	<u>Experiment</u> <u>Start Date</u>	<u>Temperature</u> <u>°C</u>	<u>Salinity</u> <u>g/kg</u>
Bedded exposure	55	4/23/85	5/9/85	10	29.3
Suspended exposure	42	4/23/85	5/3/85	10	29.3

Suspended sediment dosing system

28. Laboratory studies required the construction of two identical sediment dosing systems to provide either BRH or REF material as suspended sediment simultaneously. Each dosing system (Figure 3) consisted of a conical-shaped slurry reservoir placed in a chilled fiberglass chamber, a diaphragm pump, a 4-ℓ separatory funnel, and several return loops that directed the particulate slurry through dosing valves. The slurry reservoirs (40 cm in diameter by 55 cm high) contained 38 ℓ of slurry composed of 36 ℓ of filtered seawater and 2 ℓ of either BRH or REF sediment. The fiberglass chamber (94 cm by 61 cm by 79 cm high) was maintained between 4° and 10° C using an externally chilled water source to minimize microbial degradation during the test. Polypropylene pipes (3.8 cm diameter) extended to the bottom of the reservoir cones and were connected to pumps (16- to 40-ℓ/min capacity) fitted with Teflon diaphragms. These pumps were used to circulate the slurry while minimizing abrasion that might produce changes in the physical properties (e.g., particle size) of the material.

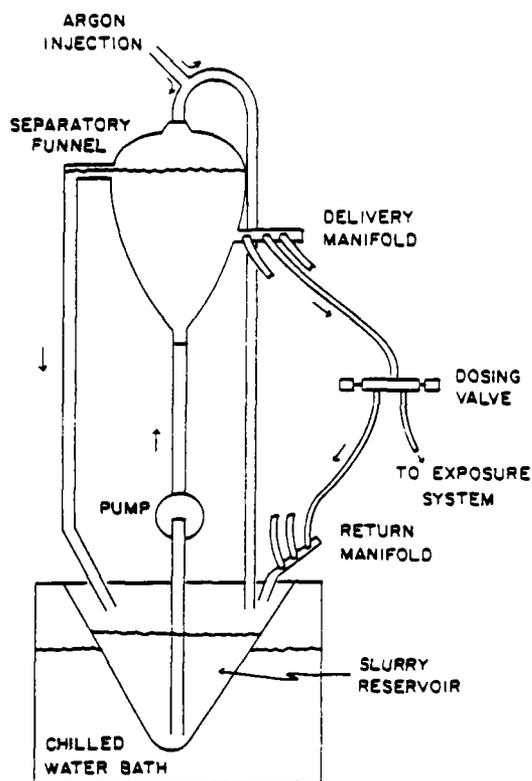


Figure 3. Suspended sediment dosing system

29. The slurry was pumped up to separatory funnels and returned via an overflow to the reservoir through polypropylene pipes. The separatory funnel provided the constant head pressure needed to circulate the slurry through Teflon tubing to the dosing valves where the slurry was mixed with seawater to provide the desired concentrations for the toxicity tests. Narragansett Bay seawater filtered (to 15 μ) through sand filters was used.

Suspended sediment oxidation system

30. The REF and BRH sediments used in the *M. edulis* tests and the *N. incisa* suspended exposure experiments were oxidized prior to introduction into the dosing system. The field collections of sediment indicated rapid oxidation of the surficial BRH sediments on the disposal mound. Since the most likely source of particulate contaminants in the water column was the oxidized surficial sediment, it was decided that laboratory exposures would be conducted with BRH sediment that had been oxidized in a consistent manner.

31. For both REF and BRH sediments, 2 l of sediment were transferred to an inverted polycarbonate carboy and diluted to 19 l with filtered natural

seawater at room temperature and aerated for 3 to 4 days (Figure 4). The contents were transferred to the composite dosing system reservoir and diluted to 38 l with natural seawater. Chemical oxygen demand measurements indicated that this time period was sufficient to satisfy the immediate oxygen demand of the sediments.

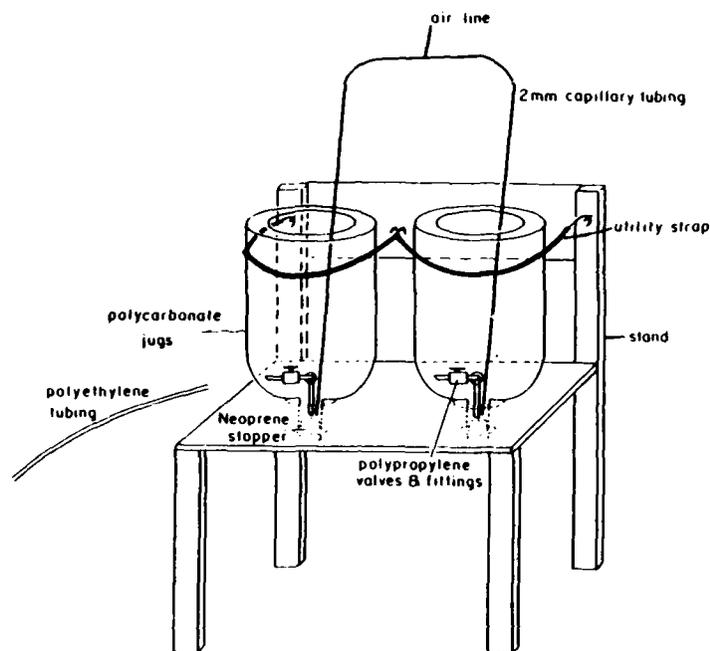


Figure 4. Suspended sediment oxidation system

Exposure system

32. *Mytilus edulis*. An exposure system was constructed to provide a constant concentration of suspended sediment to *M. edulis* in the laboratory. This system consisted of recirculating loops from the suspended sediment dosing system connected to a dosing valve at each exposure chamber. The concentration of total suspended particulates was maintained at approximately 12 mg/ml in both the REF and BRH loops. The exposure system was capable of delivering either REF sediment or BRH sediment directly into each exposure chamber via a dosing valve. The combined use of a REF and a BRH dosing valve at an exposure chamber allowed delivery of a mixture of the two sediments. The percent concentrations of BRH and REF sediment varied between treatments; however, a total suspended sediment concentration of approximately 10 mg/ml (dry weight) was maintained in all five laboratory exposure treatments. This concentration was chosen because it approximated the background field suspended sediment concentration at the CLIS disposal site.

33. Each *M. edulis* exposure chamber was equipped with a transmissometer, an instrument capable of measuring light attenuation due to suspended sediment in the chamber (Figure 5). The dosing valves for each treatment were

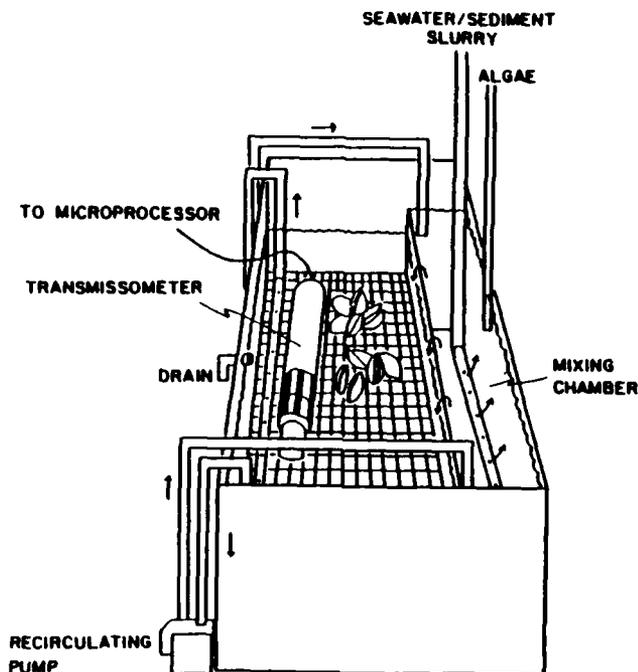


Figure 5. *Mytilus edulis* exposure system

controlled by a transmissometer-microprocessor feedback loop (Sinnott and Davis 1983). The transmissometer in each chamber was calibrated by regressing suspended sediment concentrations, measured by filtration onto glass fiber filters, with the transmissometer units displayed on a microprocessor. A transmissometer value was calculated that corresponded with the desired suspended sediment concentration of 10 mg/l for each chamber. As the *M. edulis* removed suspended sediments, the microprocessor opened dosing valves to deliver additional suspended sediment at 2-min intervals. In this manner, suspended sediment concentrations were maintained at the desired values (± 10 percent). The transmissometer circuit was also connected to a strip chart recorder, which allowed the operation of the system to be monitored continuously. Each chamber was aerated with three 25- by 2.5-cm air stones to provide sufficient oxygen and to ensure even distribution of suspended particulates (Figure 5).

34. In addition to the suspended sediment, food in the form of a unicellular alga, *Isochrysis galbana*, was supplied to each exposure chamber. Periodic measurements were made of *M. edulis* clearance rates in each chamber

to determine the volume of algae required to maintain an algal concentration of 0.5 mg/l. This concentration constituted an adequate maintenance ration for the mussels. Algae were added at 5-min intervals by means of a peristaltic pump. All experiments were conducted at 15° C with filtered seawater that flowed through each experimental chamber at a rate of 0.4 l/min. Each chamber was cleaned every other day.

35. The purpose of the laboratory experiments was to expose *M. edulis* to the range of BRH concentrations that may have been present in CLIS and to assess the accumulation of organic and inorganic contaminants in these organisms. *Mytilus edulis* were exposed for approximately 1-month periods at the CLIS disposal site; therefore, exposures of similar duration, 28 days, were used for the laboratory exposures. In addition, 28 days of exposure were found to be sufficient to attain steady-state contaminant concentrations in *M. edulis* in a previous study (Lake, Hoffman, and Schimmel 1985).

36. At the start of both experiments, 150 mussels were placed into each chamber. *Mytilus edulis* were sampled at time zero to determine initial tissue residue concentrations.

37. Experiment 1 consisted of three exposure treatments: 100-percent, 50-percent, and 0-percent BRH suspended sediment. *Mytilus edulis* were removed from each treatment on day 14 for chemical and biological analysis. Experiment 1 was terminated at day 14 because adverse biological effects (e.g., reduced filtration rate) were observed in both treatments containing BRH sediment.

38. Experiment 2 was conducted with lower concentrations of BRH suspended sediment. Exposure treatments of suspended sediment in Experiment 2 were 30-percent, 10-percent, and 0-percent BRH. Fifteen organisms were removed on days 7, 14, 21, and 28 for tissue residue analysis. Whole water chemistry samples were taken within 1 day of organism sampling. Dissolved and particulate water samples were taken within 24 hr of days 0, 14, and 28. In addition, a water sample was taken on day 29 to evaluate the performance of the system without any mussels in the exposure chambers.

39. The operation of the system (dosing valves, flow rates, etc.) was monitored daily. Experiments using the 100-percent BRH and 0-percent BRH treatment required only one dosing valve each, while the 50-percent BRH treatment required a REF and BRH valve that delivered equal amounts of suspended material. A strip chart record for each treatment indicated that the dosing

valves were operating properly. The 10-percent BRH and 30-percent BRH treatments also required two dosing valves per treatment; however, the REF and BRH dosing valves delivered different amounts of suspended material. This was accomplished by adjusting the delivery volume of each valve. The mixture of BRH and REF material was checked daily and adjusted if necessary.

40. Nephtys incisa bedded exposure. *Nephtys incisa* were exposed to bedded sediments (called the bedded exposures) at concentrations of: 0-percent BRH, 100-percent REF; 10-percent BRH, 90-percent REF; and 30-percent BRH, 70-percent REF for 55 days. Over the 55-day duration of these exposures, changes in the color (dark brown to grey) of the top 0.5 to 1.0 cm of sediment indicated changes in the oxidation state had occurred.

41. One day prior to initiation of worm exposures, the sediments were mixed on a volume-to-volume basis and placed into 24 exposure chambers, and three samples of each treatment were taken to check for homogeneity. The exposure containers were rectangular glass chambers (50 cm long × 24 cm wide × 20 cm deep) sealed with silicone glue. Approximately 10 l of treatment sediment were placed in each chamber to a depth of 8 cm. Unfiltered seawater at ambient temperatures (12° C) was provided at 200 ml/min. Seawater was delivered from an overhead trough through silastic and glass capillary tubing into an 8-cm-long glass test tube that was pushed into the sediment at one end of the exposure chamber, so that the top of the tube was flush with the sediment-water interface. This configuration ensured that water flowed over the sediment surface and out of the chamber through a screened opening at the opposite end. The water turnover rate was approximately 26 times/day.

42. On the following day (day 0), the worms were sieved from the holding sediments and evenly distributed among 27 glass bowls. Each bowl contained 5 to 10 large worms with a biomass of approximately 5 g (wet weight). The worms from each bowl were put into individual exposure chambers. *Nephtys incisa* from the remaining three bowls were frozen in clean jars for analysis. The chambers were monitored daily for water temperature and flow rates. Dead animals were removed when present.

43. Two samples of *N. incisa* and sediment were removed on days 10, 21, 28, and 55. For each *N. incisa* sample, the organisms from a single aquarium were collected by sieving the sediment. Prior to removal of *N. incisa*, sediment samples were obtained by pushing a glass jar to the bottom of the

exposure chamber and collecting the full depth of the sediment. Both organisms and sediment were frozen for analysis.

44. *Nephtys incisa* suspended exposure. In the laboratory tests with *N. incisa*, the dosing system was set to maintain nominal concentrations of 200 mg/l (dry weight) of suspended sediments with seawater flow rates producing five volume replacements per exposure chamber per day. These flow rates meet the minimum recommended by the American Society for Testing and Materials (1982) and were intended to maximize residence time of the suspended sediments in the exposure chambers.

45. A suspended sediment proportional diluter (Figure 6) was used to mix the small quantities of concentrated sediment slurries (10 to 20 g/l) from the sediment dosing system with filtered seawater to produce dilute sediment suspensions in the milligrams-per-litre range. It then combined slurries of different types (e.g., REF and BRH sediment suspensions) proportionally to maintain the same concentration of suspended sediment with different ratios of the two sediments.

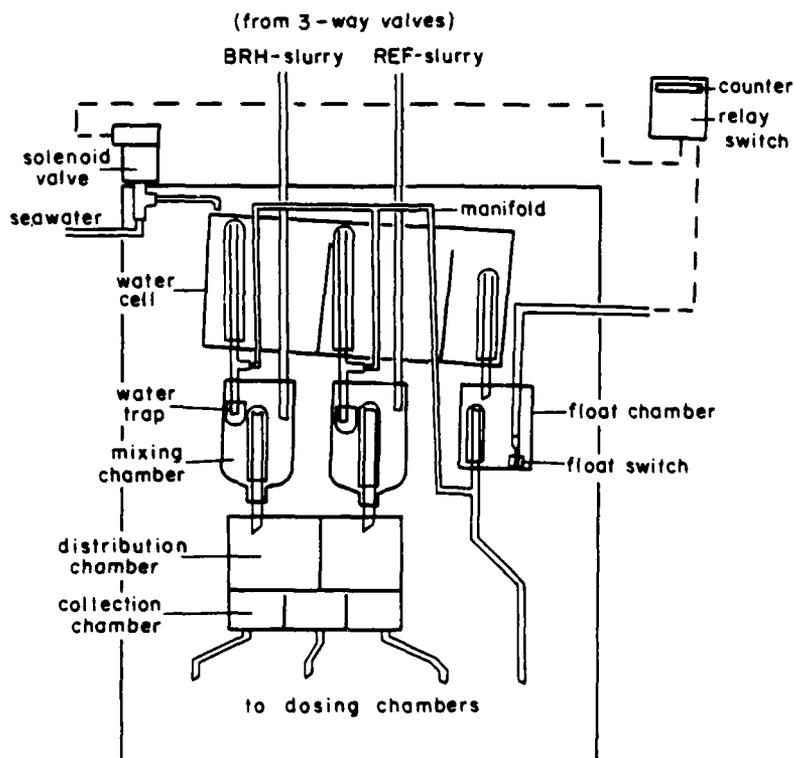


Figure 6. Proportional diluter used to deliver suspended sediment to the *N. incisa* exposure chambers

46. The exposure chamber *N. incisa* is illustrated in Figure 7. Polycarbonate bottles (19 l) used commercially for shipping spring water were cut

DOSING CHAMBER

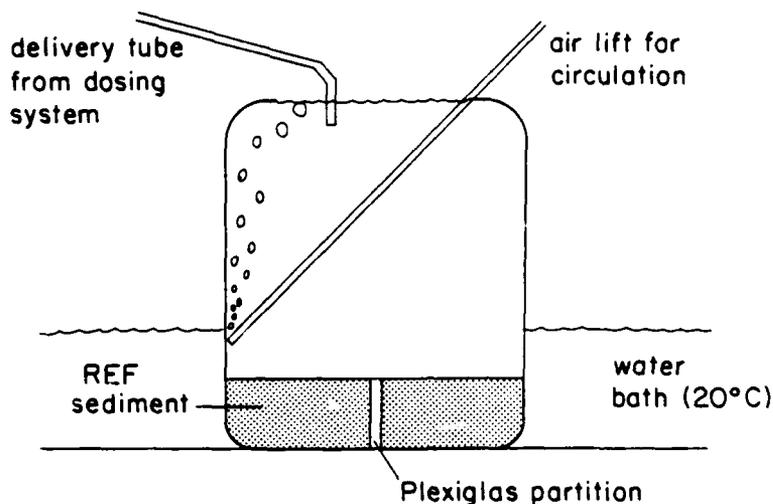


Figure 7. *Nephtys incisa* exposure chamber

off at the top. REF sediment (2 l/chamber) was added to a depth of 4 cm, and Plexiglas strips were inserted into the sediment, dividing it into pie-shaped sections. This permitted subsampling without disturbing the entire chamber. Each chamber was filled with filtered seawater at 20° C. After the sediment in the chambers was permitted to settle and equilibrate for about 4 hr, *N. incisa* were added, and an additional 2 hr was allowed for the organisms to burrow into the sediment. The delivery tubes from the proportional diluter were then put in place, and a low pressure airlift was turned on to keep the dosed sediments in suspension. This system allowed very little sediment deposition during the course of experiments. Excess seawater was permitted to overflow the brim of each chamber. Earlier experiments indicated that once the *N. incisa* burrowed into clean reference sediment, they would not attempt to escape. Therefore, the chamber design used here was considered acceptable. Two chambers were used for each of the three treatments for a total of six chambers per experiment. The two chambers did not represent replicates, but were used to accommodate enough organisms for chemical analysis in the experiment.

47. The *N. incisa* suspended exposure experiment lasted 42 days and had

exposure conditions of 100-, 50-, and 0-percent BRH suspended sediment. This experiment provided time series sampling for the three exposure conditions. *Nephtys incisa* were removed at time zero, day 28, and day 42. The experiment was supported with chemical analyses of the seawater and *N. incisa* at each sampling. *Nephtys incisa* were collected on a sieve after removal of a pie-shaped aliquot of bedded sediment from each chamber. Clean reference sediment, without *N. incisa*, was returned to the vacated section to maintain the integrity of the exposure chamber.

48. Suspended sediment, temperature, and salinity were measured routinely during the experiment. Dissolved oxygen (DO) concentrations were not expected to be a problem because of the large volume of the chamber and the use of an airlift. However, DO levels were determined once during the experiment and did not differ significantly from the expected saturation level. The *N. incisa* were fed 100 mg of powdered prawn flakes per chamber per day for the duration of this experiment.

Organism gut purging

49. Samples of *M. edulis* and *N. incisa* from the laboratory and field studies reported here were not purged prior to analysis. Studies with *M. edulis* have demonstrated that the content of sediment presented in the gut of the organism has an insignificant impact on the measured body burden of PAH and PCB contaminants (Lake, Hoffman, and Schimmel 1985).

50. Studies examining the quantity of sediment present in field-collected *N. incisa* prior to gut purging showed the worms contained only 3.8 percent \pm 1.8 percent (n = 7) dry weight of sediment (unpublished data). The organic contaminants associated with this amount of sediment were insignificant relative to the amounts accumulated by the organisms.

Field Methods

Collection of water samples

51. Organic compounds. Samples of water were obtained at stations utilizing a Teflon-lined stainless steel braided hose and a pump equipped with a Teflon impeller. The hose was lowered to the desired sampling depth, and the sampling system was flushed with water for 5 min prior to obtaining the water sample. Each sample (22 l) of water was pumped into a total of six glass bottles. The extraction of the samples was started immediately by the addition of 200 ml of CH_2Cl_2 to each bottle.

52. Inorganic compounds. Seawater samples for Cu analysis were collected from the sampling depth (1 m above the bottom) using a pump and a nylon-reinforced, clear polyvinyl chloride (PVC) hose. All parts of the pump contacting the seawater sample were made of Teflon or polypropylene. Each whole water sample (250 ml) was pumped from the sampling depth into precleaned polyethylene bottles. The samples were analyzed for Cu by methods described in paragraphs 73-75.

Organism collection and holding

53. Mytilus edulis. All *M. edulis* used in the field studies for the FVP were collected by scallop dredge from Narragansett Bay. In general, *M. edulis* were collected 1 to 2 days prior to field deployment to Long Island Sound. They were returned to the laboratory where 100 5- to 7-cm organisms were sorted and placed into each polyethylene basket. All baskets were placed in holding tanks of flowing unfiltered seawater until deployed in the field.

54. Nephtys incisa. *Nephtys incisa* for field studies were collected at stations REFS, 1000E, 400E, and CNTR. Station locations were marked with buoys for the duration of this project. While the boat was anchored, a Smith-MacIntyre grab sampler (0.1 m²) was used to collect bottom sediments. These sediments were wet sieved on deck (nested sieves of 2- and 0.5-mm mesh size) and organisms were collected, placed in sediment, and returned to the lab. The following day organisms for chemical analysis were wet sieved from the sediment and frozen.

Exposure

55. Mytilus edulis deployment and retrieval. *Mytilus edulis* were deployed at CNTR, 400E, 1000E, and REFS at the CLIS disposal site (Figure 2). The physical arrangement of each station is detailed by Phelps and Galloway (1980). In short, each station consisted of a surface buoy attached by cable to a concrete mooring on the bottom, with two smaller satellite moorings attached to the larger main mooring. A subsurface buoy was attached to each small mooring from which the mussel baskets were hung 1 m above the bottom. Two baskets were attached to each subsurface buoy at each deployment.

56. The deployments of *M. edulis* at the CLIS disposal site are summarized in Table 3. Mussels were deployed at each station for a period of 1 month predisposal to collect baseline data (cruise number T - 4). A second deployment occurred during disposal operations, except that no *M. edulis* were placed at the CNTR station (T + 0, T + 2). Mussels were deployed for 1-month

Table 3
Cruise Number, Deployment Date, Retrieval Date, and Length of
 Deployment for Mussels Transplanted to CLIS

<u>Cruise Number (Weeks)</u>	<u>Deployment Date</u>	<u>Retrieval Date</u>	<u>Length of Deployment</u>
T - 4	16 Mar 83	22 Apr 83	1 month
T + 0*	22 Apr 83	24 May 83	1 month
T + 2	23 Apr 83	07 Jun 83	6 weeks
T + 8	07 Jun 83	13 Jul 83	1 month
T + 12	13 Jul 83	10 Aug 83	1 month
T + 15	10 Aug 83	06 Sep 83	1 month
T + 21	16 Mar 83	18 Oct 83	7 months
T + 27	06 Sep 83	29 Nov 83	3 months
T + 43	29 Nov 83	20 Mar 84	3 months
T + 55	18 Oct 83	05 Jun 84	8 months
T + 74	12 Jun 84	17 Oct 84	4 months
T + 116	11 Jul 85	14 Aug 85	1 month

* T + 0 refers to the termination of disposal activities at the FVP site on 18 May 1983.

periods over the next 3 months (T + 8, T + 12, T + 15) and then on approximately a quarterly basis through T + 74. The last field deployment was collected at T + 116. In addition, several sets of mussels were left at each station for 7 months (T + 22). *Mytilus edulis* were retrieved from the sub-surface buoys by divers, and those used for chemical analysis were frozen immediately.

57. *Mytilus edulis* field exposures via tissue residues. Exposure conditions present in the field during each mussel deployment were not as well characterized as they were in the laboratory studies. As a result, the description of *M. edulis* exposure to BRH material in the field is more qualitative than quantitative and will be presented in two parts. First, a prediction of field exposure is based on mussel tissue residues. The relationship between exposure to BRH sediments and tissue residues was determined in the laboratory experiments. Tissue residues of PCBs from the 0-, 10-, and 30-percent BRH treatments at 28 days were regressed against measured BRH

exposure concentrations (0, 1.5, 3.3 mg/l) from the same exposures. In order to correct for background residues in the laboratory, the PCB concentration of the 0-percent BRH treatment was subtracted from the others prior to regression analysis. The relationship was

$$\text{BRH material} = (\text{PCB} \times 0.000965) - 0.0019 \quad (R^2 = 0.999) \quad (1)$$

where BRH material is in milligrams per litre and PCB is the organism residue in nanograms per gram (dry). This relationship was used to calculate the average sustained concentration of BRH material necessary to achieve the residue value obtained in the field.

58. The estimated BRH exposure levels in the field were determined by substituting the mussel PCB tissue residue concentration directly into the above equation. This estimate was assumed to represent an upper range of suspended BRH material present. A second estimate was determined by first subtracting the PCB concentration in mussels at the REFS station from the other stations during that collection. This removed the Long Island Sound background PCB levels from the estimates, and thus was assumed to represent a lower range of BRH present in CLIS. This procedure was completed for each collection date and station that mussels were retrieved.

59. Mytilus edulis field exposures via water chemistry data. A second estimate of exposure was generated from the PCB and copper concentrations in the whole water samples collected during various postdisposal cruises. The concentration of BRH material that would have to be present to produce these levels was determined by dividing the concentration of PCB and copper present in the water by the concentration of these contaminants present in the barrel material collected in BRH (2900 µg/g and 6910 ng/g for copper and PCB, respectively). A range of exposures was also calculated for the water chemistry date; estimated BRH material was determined with and without subtracting the concentration at the REFS station.

60. Nephtys incisa field exposure via tissue residues. The exposure conditions present in the field for *N. incisa* were not as well characterized as they were in the laboratory studies. As a result, the description of *N. incisa* exposure to BRH material in the field is more qualitative than quantitative and is presented in three parts. First, a prediction of field exposure is based on *N. incisa* tissue residues. The relationship between

exposure to BRH material and concentrations of tissue residues of PCBs and SUM (see paragraph 71) in *N. incisa* from the bedded exposures was developed using the tissue residue concentrations in *N. incisa* exposed to 0-, 10-, and 30-percent BRH in laboratory tests. The relationships were

$$\% \text{ BRH} = (\text{PCB} \times 48.8) - 8.4 \quad (R^2 = 0.864) \quad (2)$$

$$\% \text{ BRH} = (\text{SUM} \times 3.82) - 3.4 \quad (R^2 = 0.975) \quad (3)$$

where PCB and SUM are organism residue in micrograms per gram. Also, tissue residue concentrations of PCBs in *N. incisa* exposed to 0-, 50-, and 100-percent BRH material in the suspended exposure laboratory tests were plotted against BRH exposure concentration. These relationships and the residues of contaminants in *N. incisa* from the field were used to estimate field BRH exposure concentrations.

61. *Nephtys incisa* field exposures from physical data. The second analysis described represents a simple calculation (SIC for suspended interface calculation) to predict the maximum total suspended solids concentrations from 1 m above the bottom to the sediment-water interface. This analysis assumes that the suspended solids are composed totally of BRH sediments and represents a worst case or upper bound prediction. A third, more realistic calculation, predicts the probable amount of BRH sediment exposure at the sediment-water interface based upon the actual contaminant concentrations for each sampling station and date. This analysis assumes that resuspension of the surface sediment is the primary source of the total suspended solids at the sediment-water interface.

62. The equation used to calculate total suspended solids concentrations from the sediment-water interface up to 1 m above the bottom is described below:

$$C_z = C_m \left[1 + (C_o - 1) e^{-kz} \right] \quad (4)$$

where

C_z = total suspended solids concentration at distance z

C_m = total suspended solids concentration at 1 m above the bottom

C_o = enrichment factor (C_z/C_m when $z = 0$)

$-k$ = rate of change in total suspended solids concentration

z = distance from the bottom, m

Given the total suspended solids concentration at 1 m above the bottom, the equation predicts an exponential increase in suspended solids concentration at distances from 1 m above the bottom to the sediment-water interface.

63. The total suspended solids concentrations for these analyses were selected to represent average and storm conditions empirically determined from an in situ continuous monitoring platform deployed 1 m above the bottom at the disposal site (Bohlen and Winnick 1986; Munns et al. 1986). Enrichment factors were likewise empirically determined from acoustic profilometer data collected between the sediment-water interface and 1 m above the bottom (Bohlen and Winnick 1986; Munns et al. 1986).

64. For the purposes of the maximum upper bound analyses, it was assumed that the exposed populations are located off the mound and aligned with the mean direction of current flow. The route of contaminant exposure is assumed to be through to transport of resuspended BRH sediments. These total suspended solids are composed of resuspended Long Island Sound sediments, as well as BRH sediment resuspended from the disposal site. Since the intent of these analyses is to create a maximum upper bound set of exposure conditions, it was assumed that the suspended solids concentration was composed, in total (100 percent), of resuspended BRH sediment.

65. It was not within the scope of this program to provide a continuous temporal record of the percent contribution of BRH sediments to the total suspended solids load. Consequently, a second set of analyses was designed to estimate the percentage of BRH sediment that could have comprised the total suspended solids concentration at the sediment-water interface for each station and how these concentrations changed with time throughout the study. The proportions of BRH dredged material in the surficial sediments at each station and date were estimated by comparing the concentrations of selected contaminants measured in the 0- to 2-cm layer of sediment cores collected postdisposal at the FVP site. These field concentrations were compared with the barrel concentrations to determine a percentage as follows:

$$\text{Percentage BRH Sediment} = (C - \text{REF}/\text{BRH} - \text{REF}) \times 100 \quad (5)$$

where

C = concentration of contaminant in the dredged sediment

REF = concentration of contaminant in REF sediment

BRH = concentration of contaminant in BRH sediment (barrel)

The percentage BRH sediment values were calculated for each station and date using the 11 different contaminants, the details of which are shown in Appendix A, Table A1-A13. To achieve a BRH-suspended sediment concentration that reflects the surficial sediment contaminant levels for each station and date, the total suspended solids concentrations predicted for the sediment-water interface (using Equation 4) were multiplied by the estimated proportions of BRH sediment.

Chemical Methods

Analytical methods

66. The analytical methods used in this study are presented here in summary form. More detailed descriptions of the analytical methods are available in Appendix B. Most of these methods represent extensive modifications of USEPA standard methods developed for freshwater and wastewater samples. It was necessary to modify these methods in order to analyze the types of matrices in this study. These methods were intercalibrated to ensure the quality of the data (Galloway et al. 1983). Analytical variability is no greater than 20 percent in all of the reported results.

Organic analysis

67. Sample preparation. Samples of sediment, suspended particulates, and organisms were extracted by multiple additions of increasingly less polar organic solvents using a tissue homogenizer. These mixtures were separated by centrifugation between additions; polar solvents were removed by partitioning against water; and sulfur compounds were removed with activated copper powder when required. The extracts were then passed through a column containing activated silica gel. Samples of both filtered and unfiltered seawater were solvent extracted in separatory funnels, and the extracts were saved. Foam plugs containing the dissolved organic contaminants from water samples were extracted with organic solvents. All of the above extracts were subjected to column chromatography on deactivated silica gel to separate analytical fractions and were volume reduced carefully prior to analysis.

68. Instrumental analysis. Electron capture gas chromatographic analyses for PCBs were conducted on a Hewlett-Packard 5840 gas chromatograph equipped with a 30-m DB-5 fused silica column. Samples were quantified against an Aroclor 1254 (A1254) standard because the distribution of PCB congeners in the dredged material closely matched that distribution, as did the distribution in organisms at steady-state.

69. Gas chromatograph/mass spectrometric analyses were conducted with a Finnigan Model 4500, also equipped with a 30-m DB-5 fused silica capillary column. The mass spectrometer was operated through a standard Incos data system and was tuned at all times to meet USEPA quality assurance specifications.

70. All instruments were calibrated daily with the appropriate standards. The concentrations of the standards used were chosen to approximate those of the contaminants of interest, and periodic linearity checks were made to ensure the proper performance of each system. When standards were not available, response factors were calculated using mean responses of comparable standards. Blanks were carried through the procedure with each set of samples, and reference tissue homogenate was analyzed with every 12 to 15 tissue samples.

71. Data compression. As stated above, PCBs were quantified as A1254 because the sample patterns (the relative abundances of constituents within a sample) closely resembled that profile. This allowed a convenient way of reporting these data without treating the voluminous data that would have resulted from measuring some 55 congener peaks by electron capture detector. Likewise, a method was sought to summarize the PAH data. Appendix C lists the 35 individual PAH parent and alkyl homolog compounds and groups of compounds measured in this study. Each PAH of the same molecular weight, both parents and alkyl homologs, can be summed to yield 9 PAH parent sums and 5 alkyl homolog sums. Although useful, this only reduced the data to 14 PAH variables, which was not sufficient. Since the distribution of PAHs differed greatly in both quantity and quality between Long Island Sound and the BRH dredged material, statistics were sought which would retain significant quantitative and qualitative information. The quantitative statistic chosen was the simple SUM of all measured PAHs, and a qualitative descriptor was chosen by analogy with the center of mass concept from elementary physics and called a centroid (CENT):

$$\text{SUM} = \sum [C(i)] \quad (6)$$

$$\text{CENT} = \frac{\sum [C(i) * \text{MW}(i)]}{\text{SUM}} \quad (7)$$

where

$C(i)$ = concentration of i -th PAH from molecular weight 166 through 302, including both parent and alkyl homologs

$\text{MW}(i)$ = molecular weight of i -th PAH from 166 through 302, including both parent and alkyl homologs

In this case, CENT describes the "center of mass" of the PAH distribution, and is in units of molecular weight. It is the concentration-weighted average molecular weight of any particular PAH distribution. This statistic can be used to readily distinguish two different sources of PAH distributions, one with predominately heavy molecular weight pyrogenic compounds, and one with more lighter molecular weight petrogenic compounds. These distributions are typically found in Long Island Sound at REFS and BRH, respectively. A major value of this statistic is that it enables one to readily distinguish these two sources when their concentrations are nearly equal. The formulas for calculating these, and 178 alkyl homologs, are shown in Appendix C. Because distributions of both parents and homologs were measured, SUMs and CENTs of both parents and homologs were calculated as well. These were defined as PSUM, PCENT, HSUM, and HCENT. By definition,

$$\text{SUM} = \text{PSUM} + \text{HSUM} \quad (8)$$

$$\text{CENT} = \frac{(\text{PSUM} * \text{PCENT} + \text{HSUM} * \text{HCENT})}{\text{SUM}} \quad (9)$$

Inorganic analysis

72. Sample preparation. Sediment was prepared for inorganic analysis by elution at room temperature with 10% HNO_3 . The samples were filtered through Whatman #42 filter paper. Organisms were totally digested in concentrated HNO_3 at 60° C and filtered through Whatman #42 filter paper.

73. Cadmium, copper, nickel, and lead were concentrated and separated from both the unfiltered and filtered seawater fractions by coprecipitation (Boyle and Edmond 1975). The remaining metals (chromium, iron, manganese, and zinc) were analyzed by heated graphite atomization atomic absorption (HGA-AA)

via direct injection. Samples of suspended particulates on Nucleopore (0.45 μ) filters were eluted with 2N HNO₃ and analyzed by HGA-AA.

74. Instrumental analysis. All flame atomization atomic absorption (FA-AA) was conducted with a Perkin-Elmer Model 5000 atomic absorption spectrophotometer. All HGA-AA determinations were conducted with Perkin-Elmer Model 500 or 2100 HGA units coupled to Perkin-Elmer Model 5000 or 603 atomic absorption instruments, respectively. The Model 5000 AA was retrofitted with a Zeeman HGA background correction unit, and the Model 603 was equipped with a deuterium arc background correction system.

75. The FA-AA and HGA-AA instrument operating conditions are similar to those described in USEPA (1979) and those in the manufacturers' reference manuals. The AA instruments were calibrated each time samples were analyzed for a given element. Sample extracts were analyzed a minimum of twice to determine signal reproducibility. Quality assurance checks, conducted after every 15 samples, were analyzed by the method of standard addition and by analyzing one procedural blank. One reference tissue homogenate sample was analyzed with each 15 to 20 organism samples.

Contaminant selection

76. Chemical analyses performed in this study characterize the organic and inorganic constituents in the dredged material, provide information on the laboratory and field exposure environments, provide insight into the processes governing contaminant movement within and between environmental compartments, and determine which contaminants were accumulated by organisms. In determining the acceptability of dredged material for ocean disposal, a variety of evaluatory criteria are applied. These include bulk sediment chemistry, toxicity, and bioaccumulation. In this study, bioavailability was determined by examining the types and distributions of contaminants that bioaccumulated in laboratory studies (Rogerson, Schimmel, and Hoffman 1985). Based upon the contaminant profile for the dredged material and residue data, the contaminants selected for detailed analyses throughout the study included PCBs, PAHs, the pesticide ethylan, and eight metals.

77. A representative subset of chemicals was selected for discussion throughout the study. The criteria used in selecting this subset included chemical properties, contaminant representativeness and behavior in various compartments, and statistical analyses of the distributions of the complete suite of chemicals analyzed in the program.

78. Multivariate clustering analyses were performed on the chemical data in an attempt to define groups or clusters of chemicals that behaved in a statistically similar manner. No assumptions were made concerning the behavior, interactions, or dynamics of chemicals between compartments; therefore, each compartment was analyzed separately. Five compartments were identified from field and laboratory data for statistical analysis. Of these, the surficial sediments and the unfiltered, particulate, and dissolved water column fractions described exposure conditions experienced by infaunal and pelagic organisms. The remaining compartment consisted of tissue residues in organisms.

79. The data were further partitioned into inorganic and organic analysis. The inorganic analyses generally consisted of 8 variables, while the organic analyses contained 61 variables. The clusters of chemicals identified through the statistical analyses agreed well with those contaminants selected based on chemical properties and environmental behavior.

Statistical Analysis

80. The primary objective of the FVP was to compare laboratory and field responses under similar exposure conditions. Because of the highly dynamic temporal and spatial conditions in the field, the exposure environment can be given only boundaries and cannot be assigned specific values, as is the case for laboratory studies. Consequently, the degree to which laboratory exposure-response relationships concur with those derived from field data can be described only qualitatively. That does not preclude the use of inferential statistical procedures to explore those laboratory and field relationships for which the appropriate quantitative information is available. However, the nature of this project was such that descriptive and exploratory statistics were often the most appropriate techniques to illustrate relations and trends. Simple graphic representations of variables were all that was necessary to illustrate a relationship. In addition, multivariate techniques, such as cluster analysis, were the most appropriate techniques to elucidate more complex relationships between groups of selected variables.

81. In the laboratory experiments, regression analysis was used to determine the relationship between residues accumulated and BRH exposure concentration (Snedecor and Cochran 1967). The limited exposure data from CLIS

precluded measuring similar relationships for the field organisms.

82. The similarities of laboratory and field exposures were examined. This analysis assumes that tissue residue and exposure are closely related and was accomplished by examining the tissue residues of all *M. edulis* and *N. incisa* from laboratory and field exposures together, independent of exposure concentration or station location and date. The PCB, ethylan, PAH, and SUM and CENT variables were analyzed by cluster analysis (SAS 1985) to establish which tissue residues among all the laboratory treatments and field stations were most similar. The clustering procedure used was the average linkage method, which uses unweighted pair-groups with arithmetic averages on squared distances between samples. Prior to analysis, residue values for each compound were normalized using standard deviations from the mean. This procedure ensured that each variable was weighted equally, even if its absolute value was orders of magnitude different from another variable.

PART III: RESULTS

83. In the results and discussion sections that follow, comparisons are made of the occurrence of compounds and their relative concentrations, as indicated for PCBs in electron capture gas chromatograms, and for PAHs and ethylan in bar graphs. In the chromatograms, molecular weight increases from left to right, and the identities of labeled peaks are shown in Table 4. In the bar graphs, the parent compounds are indicated by solid bars. The abundance of the alkyl homologs is shown as empty bars to the right of the parent compounds. The molecular weight range of these plots is from 178 to 302. At the extreme right of the graphs, bars labeled "223" are used to represent ethylan. Table 5 gives the identities of the compounds represented by the bars in Figure 8.

84. In this report, "pattern" is used to describe relative abundances of constituents in a sample. These patterns are shown by the heights or peaks or bars in the figures. "Distribution" is used to refer to the molecular weight range of the compounds present in a sample.

85. Table 6 lists the concentration of the ten selected contaminants and two summary statistics for both BRH barrel material and REF sediments. It clearly demonstrates the large differences in the contaminant concentrations in the two sediments, illustrating the contaminants that are useful as tracers of BRH material within CLIS and the laboratory experiments.

Laboratory

Exposure - *Mytilus edulis*

86. System monitoring. The *M. edulis* exposure system was monitored for both total suspended solid (TSS) concentrations and the percentage of REF and BRH sediments. The strip chart record indicated that the system maintained a suspended particulate concentration of 10 mg/l approximately 90 percent of the time. Examples of times when the 10 mg/l was not maintained include periods when exposure tanks were cleaned, slurry reservoirs were changed, and lines were clogged. Overall, the system provided a nearly constant total suspended particulate concentration to the *M. edulis*. The concentration of BRH and REF sediments dosed into each treatment is listed in Table 7.

Table 4

Tentative Identifications of Compounds in Electron Capture
Detector Gas Chromatograms*

Peak #	Tentative Identification
1	2,3-dichlorobiphenyl
2	Dichlorobiphenyl
3	Dichlorobiphenyl
4	2,2',5-trichlorobiphenyl
5	Trichlorobiphenyl
6	Trichlorobiphenyl
7	Trichlorobiphenyl
8	Trichlorobiphenyl
9	2,4',5-trichlorobiphenyl
10	2,4,4'-trichlorobiphenyl
11	2,3,4-trichlorobiphenyl
12	Trichlorobiphenyl
13	Trichlorobiphenyl
14	Tetrachlorobiphenyl
15	2,2',4',5,-tetrachlorobiphenyl
16	2,2',4,4'-tetrachlorobiphenyl
17	2,2',3',5-tetrachlorobiphenyl
18	Tetrachlorobiphenyl
19	Tetrachlorobiphenyl
20	Tetrachlorobiphenyl
21	2,3',4',5-tetrachlorobiphenyl
22**	2,3',4,5',6-pentachlorobiphenyl, 2,3',4,4'- tetrachlorobiphenyl, 2,2',3,5,5-pentachlorobiphenyl
23	Pentachlorobiphenyl, 2,3,8-trichlorodibenzofuran, tetrachlorodiphenyl ether
24	Tetrachlorobiphenyl, Pentachlorobiphenyl
25	2,2',4,5,5'-pentachlorobiphenyl
26	Pentachlorobiphenyl
27	Pentachlorobiphenyl
28	Pentachlorobiphenyl, 1,1-bis (p-chlorophenyl) - 2,2-dichloroethylene
29	Pentachlorobiphenyl
30	Pentachlorobiphenyl
31	Pentachlorobiphenyl, Hexachlorobiphenyl
32	Pentachlorobiphenyl, Hexachlorobiphenyl
33	Pentachlorobiphenyl

(Continued)

* Since all PCB isomer standards were not available, the possibility exists that other isomers may elute with identical retention times as the PCB in this table. Therefore, the authors prefer the conservative approach by listing identifications as tentative.

** More than one PCB isomer standard with this retention time eluted in this position.

Table 4 (Concluded)

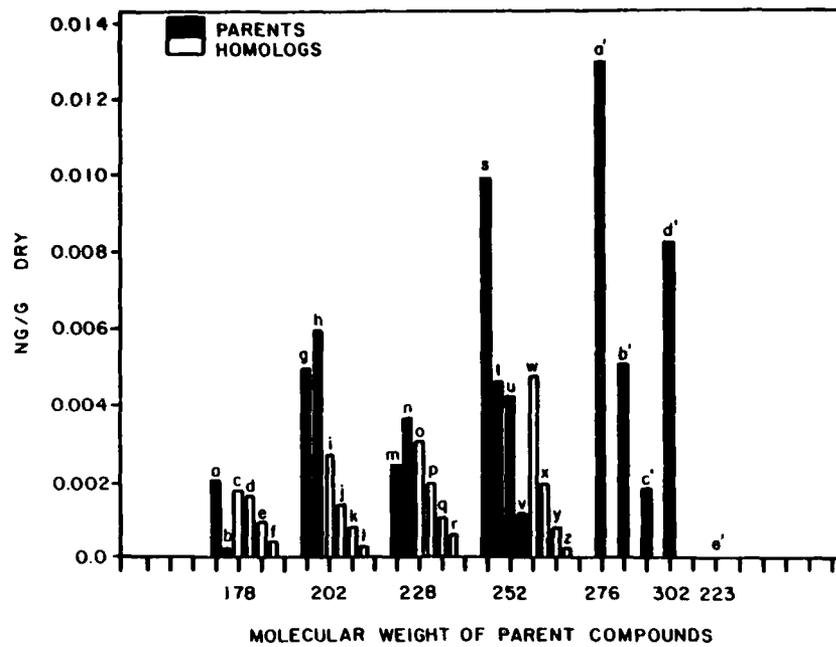
Peak #	Tentative Identification
34	Pentachlorobiphenyl, Hexachlorobiphenyl
35	Hexachlorobiphenyl
36	2,2',4,4',5,5'-hexachlorobiphenyl
37	Pentachlorobiphenyl, Hexachlorobiphenyl
38	Hexachlorobiphenyl
39	Hexachlorobiphenyl
40	2,2',3,3',4,5-hexachlorobiphenyl
41	Heptachlorobiphenyl
42	2,2',3,4,4',5',6-heptachlorobiphenyl
43	2,2',3,3',4,4'-hexachlorobiphenyl
44	Hexachlorobiphenyl
45	Heptachlorobiphenyl
46	2,3,3',4,4',5-hexachlorobiphenyl
47	2,2',3,3',4,5',6,6'-octachlorobiphenyl
48	2,2',3,4,4',5,5'-heptachlorobiphenyl
49	Heptachlorobiphenyl
50	Octachlorobiphenyl
51	Octachlorobiphenyl
52	2,2',3,3',4,4',5,5'-octachlorobiphenyl
53	2,2',3,3',4,4',5,5',6-nonachlorobiphenyl
54	Decachlorobiphenyl

Table 5
Identities of Compounds Represented by Bars in Bar
Graphs of PAH and Ethylan Concentrations

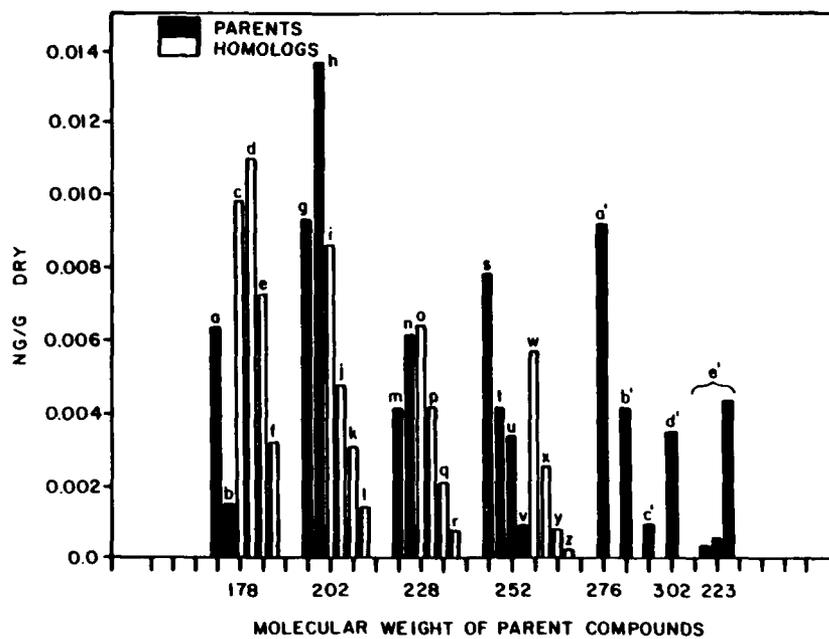
<u>Letter</u>	<u>Compound</u>
a	Phenanthrene
b	Anthracene
c	Sum of 178's with one alkylation
d	Sum of 178's with two alkylations
e	Sum of 178's with three alkylations
f	Sum of 178's with four alkylations
g	Fluoranthene
h	Pyrene
i	Sum of 202's with one alkylation
j	Sum of 202's with two alkylations
k	Sum of 202's with three alkylations
l	Sum of 202's with four alkylations
m	Benzo[a]anthracene
n	Chrysene
o	Sum of 228's with one alkylation
p	Sum of 228's with two alkylations
q	Sum of 228's with three alkylations
r	Sum of 228's with four alkylations
s	Benzo[b]+benzo[k]fluoranthene
t	Benzo[e]pyrene
u	Benzo[a]pyrene
v	Perylene
w	Sum of 252's with one alkylation
x	Sum of 252's with two alkylations
y	Sum of 252's with three alkylations
z ₁	Sum of 252's with four alkylations
a ₁	Parent PAH with molecular weight of 276
b ₁	Parent PAH with molecular weight of 278
c ₁	Parent PAH with molecular weight of 300
d ₁	Parent PAH with molecular weight of 302
e	Ethylan

87. When the TSS concentration dropped in the 50-percent BRH exposure tank, a pulse of equal length was sent to both the REF and BRH dosing valves. Volumetric measurements of the BRH and REF sediment doses indicated that equal amounts (± 5 percent) of BRH and REF material were delivered to the 50-percent BRH exposure chamber. The 100-percent BRH and 0-percent BRH treatments were controlled by single dosing values.

88. The 10- and 30-percent BRH treatments required two dosing valves per treatment. Because the pulse length could not be adjusted separately for each valve, manual adjustment of each valve was required to provide the



a. 0% BRH



b. 30% BRH

Figure 8. Bar graphs of PAHs and ethylan in whole water samples from the second *M. edulis* experiment

Table 6

Concentrations of the Ten Selected Contaminants and Two Summary Statistics
for Both BRH and REF Sediments (Means \pm Standard Deviations)

Chemical Compound	Sediment*	
	BRH	REF
Phenanthrene	5,000 \pm 1,800 (8)**	85 \pm 17 (12)
Sum of 178 alkyl homologs	28,000 \pm 8,300 (15)	170 \pm 26 (12)
Fluoranthene	6,300 \pm 1,300 (15)	240 \pm 33 (12)
Benzo(a)pyrene	3,900 \pm 970 (15)	250 \pm 28 (12)
Ethylan	4,000 \pm 820 (15)	0 \pm - (12)
PCB as A1254	6,400 \pm 840 (15)	39 \pm 4 (12)
SUM of PAHs	142,000 \pm 30,000 (15)	4,500 \pm 510 (12)
CENT of PAHs	232.8 \pm 1.7 (15)	249.2 \pm 1.7 (12)
Copper	2,900 \pm 310 (18)	60 \pm 3 (15)
Cadmium	24 \pm 0.6 (18)	0.23 \pm 0.04 (15)
Chromium	1,480 \pm 83 (18)	50 \pm 15 (15)
Iron	31,000 \pm 2,800 (18)	21,000 \pm 1,400 (15)

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENT.

** (N) = number of replicates.

Table 7

Suspended Sediment Concentrations in the *M. edulis* Exposure System

Nominal % BRH	Measured Percent BRH	Resultant BRH Sediment mg/l
100	100 (0.0)*	10.0
50	50 (0.83)	5.0
30	33 (0.84)	3.3
10	15 (1.39)	1.5
0	0 (0.0)	0.0

* Standard error in parentheses.

desired concentration. The volumetric amount of BRH and REF material delivered to each treatment was monitored and recorded (Table 7). In the treatment with a nominal 10-percent BRH, the actual value delivered was 15 percent. In the 30-percent BRH treatment, the actual value was 33-percent BRH.

89. Chemical monitoring. The results of the chemical monitoring are prefaced by a brief restatement of the purpose of the exposure system in order to aid in the understanding of the results. The system used in this experiment was designed to maintain a constant particulate concentration of 10 mg/l in the exposure chambers. Initially, 150 animals were placed into each chamber with clearance rates of approximately 2 l/mussel/hr, or a total of 300 l/hr. The seawater flow rate through each chamber, independent of suspended sediment additions, was approximately 24 l/hr. To compensate for sediment removed by the mussels and to maintain a suspended particulate concentration of 10 mg/l, the dosing values added the appropriate concentration of BRH to the system. This has important consequences on the behavior of the contaminants in the exposure system.

90. If all the contaminants were associated with the suspended sediment, the contaminant concentrations in the exposure chambers should be similar to those predicted by regressing the TSS concentrations with contaminant concentrations in the BRH material. Conversely, any contaminants that do not remain bound to the particulates could attain concentrations in the exposure system different from those predicted from the TSS data. This occurs because the *M. edulis* are very efficient at removing the particulates from the water that passes through their gills. This theory is proposed to explain the measured chemical concentrations in the exposure system, using PCB and copper as examples.

91. Whole water samples were taken for chemical analysis on days 1, 7, 14, 21, and 28 in the second experiment. The mean PCB concentrations for the five sampling dates for each exposure treatment in the second experiment are given in Table 8. Based on a PCB concentration of 6 ng/g in BRH sediment, these PCB concentrations would indicate BRH concentrations of 0.2, 1.8, and 3.8 ng/l in the 0-, 10-, and 30-percent treatment respectively. This corresponds very closely to the 0-, 1.5-, and 3.3-ng/l BRH concentrations measured for these treatments. These data suggest that PCB concentrations in the system are closely related to the TSS concentrations.

Table 8
Chemical Monitoring of the Exposure System in Experiment 2

Nominal Treatment Concentration % BRH	PCB Concentration, ng/ℓ	BRH Concentrations, mg/ℓ	
		Estimated from PCB Concentrations	Measured
0	2.2	0.2	0.0
10	12.0	1.8	1.5
30	24.0	3.8	3.3

92. Copper concentrations were measured both with and without mussels in the exposure system at 10 mg/ℓ TSS for each treatment. With no mussels in the exposure system, the total copper concentrations were 9.37 and 2.5 µg/ℓ for the 30- and 10-percent BRH treatments, respectively. These concentrations represent 3.8 and 1.8 mg/ℓ BRH sediment in the two treatments, respectively. Under these conditions, the predicted and measured copper concentrations were comparable. This resulted because the effective flow of suspended sediment and incoming seawater is the same. The only loss of TSS was out the overflow due to seawater flow rates.

93. When *M. edulis* were present in the system, the mean copper concentrations were 17.0 and 10.7 µg/ℓ for the 30- and 10-percent BRH treatments, respectively. These copper concentrations correspond to 68- and 43-percent BRH sediment in the two treatments, respectively, and are higher than those expected from the TSS data. These results may be explained by the fact that copper was disassociated from the TSS and, due to its solubility in seawater, accumulated in the exposure chamber while the particulates were removed by the *M. edulis*.

94. The present study found that the distribution of PCBs in filtered water from Experiment 2 showed a greater abundance of low molecular weight PCBs than the distribution of PCBs from the filter. This indicated that the more water-soluble PCBs tended to be in the filtered water while the less water-soluble PCBs tended to remain on particles. For brevity, chromatograms of these distributions are not shown and the reader is referred to the earlier work for a more detailed description of contaminant partitioning in the dosing system (Lake, Hoffman, and Schimmel 1985).

95. Representative patterns of PAHs and ethylan in water samples from

the second experiment with *M. edulis* are shown in Figure 8. The pattern in the 0-percent BRH chamber showed the 178 and 202 alkyl homologs below the parent compounds phenanthrene (178), fluoranthene (202), and pyrene (202), respectively. Maximum concentrations were found for the 276 to 302 molecular weight PAHs. No ethylan was present. The patterns in the water samples from the 10-percent and 30-percent BRH tanks were similar to each other and showed a relatively higher content of alkyl homologs of 178 and 202 PAHs than was found in the 0-percent BRH chamber, an abundant pattern of molecular weight 276 to 302 PAHs, and the presence of ethylan.

Exposure-Nephtys incisa

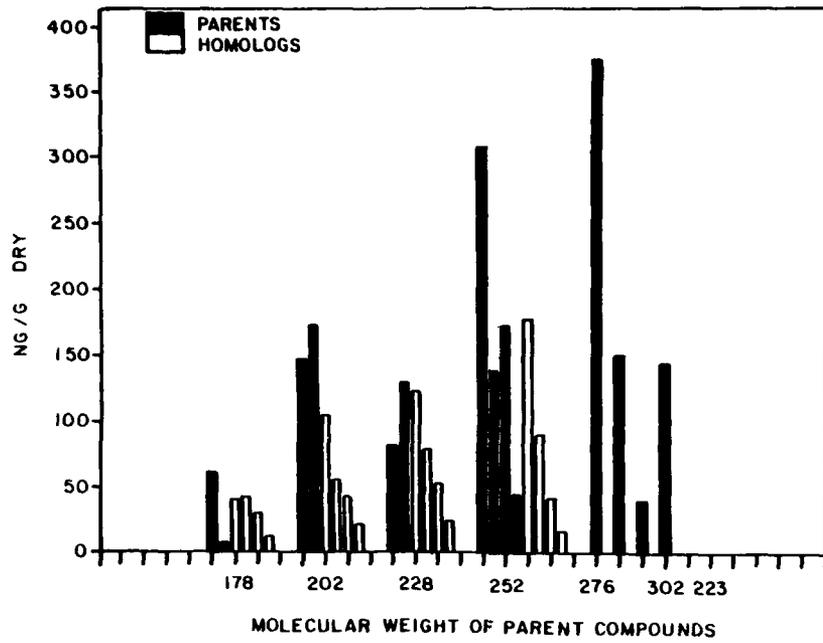
96. System monitoring. During the laboratory suspended sediment experiments with *N. incisa*, the exposure system was monitored for TSS, temperature, and salinity. These data are presented in Table 9. In general, the exposure system maintained the suspended solids concentrations close to the nominal 200 mg/l. Temperature and salinity values were stable at approximately 20° C and 30 g/kg, respectively. Dissolved oxygen concentrations were checked once during the experiment and did not differ from the expected saturation value.

Table 9

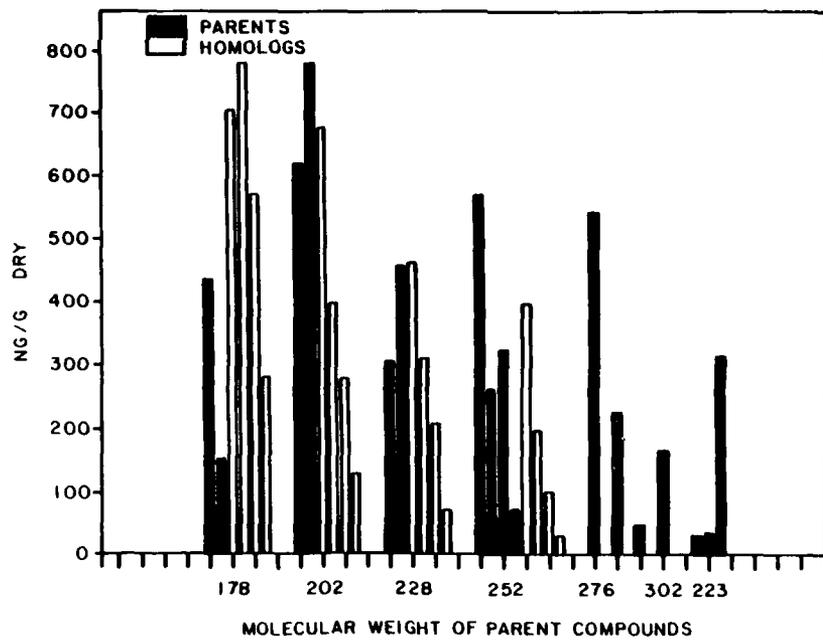
Measured Suspended Particulate Concentrations (Dry Weight) and Exposure Conditions for Laboratory Test with *N. incisa*
(Means ± Standard Deviations)

<u>Temperature % BRH</u>	<u>Concentration, mg/l Suspended Particles</u>	<u>Seawater Temperature</u>	<u>Seawater Salinity, g/kg</u>
100	201 ± 23	19.8 ± 0.53	30.9 ± 0.70
50	184 ± 19	19.8 ± 0.53	30.9 ± 0.70
0	190 ± 21	19.8 ± 0.53	30.9 ± 0.70

97. Chemical monitoring. The patterns of PAHs and ethylan present in REF sediments from the bedded sediment exposures did not change during the study (Figure 9). Ethylan was not found in these REF sediments. The 10-percent BRH and 30-percent BRH sediments both showed a relative increase in abundance of molecular weight 178 and 202 parents and homologs compared with the REF sediment. Ethylan was found in these sediment samples. These patterns remained uniform during the study. The concentrations of PCBs and PAHs in these sediments during the study are shown in Table 10.



a. 0% BRH



b. 30% BRH

Figure 9. Bar graphs of PAHs and ethylan in sediment samples from *N. incisa* bedded exposure laboratory studies

Table 10
PCB (as Al254 (ng/g dry)) and SUM of PAH Concentrations (ng/g dry)
in Sediment from *N. incisa* Bedded Exposure Study
(Means \pm Standard Deviations)

Treatment % BRH	PCBs	SUM of PAHs
0	33.6 (\pm 7.8) (n = 4)	2,260 (\pm 580) (n = 4)
10	550 (\pm 45) (n = 4)	6,780 (\pm 1,230) (n = 4)
30	1340 (\pm 71) (n = 4)	19,300 (\pm 4,880) (n = 4)

98. During the 42-day suspended exposure experiment, seawater and *N. incisa* from the exposure chambers were sampled for chemical analysis. Seawater chemical monitoring data are presented in Table 11. The dosing system malfunctioned for 2 days spilling BRH sediments into all treatments. The day 18 chemistry samples were taken during this period. The problem was corrected, and for the remainder of the test the system performed normally. The chemistry data confirm that *N. incisa* received a graded exposure to BRH sediments.

Tissue residue - *Mytilus edulis*

99. PCB patterns. The PCB tissue residues in the day 0 *M. edulis* from both Experiment 1 and Experiment 2 show a pattern of peaks typical of *M. edulis* from the lower Narragansett Bay reference population. The pattern of PCBs present in these organisms is dominated by compounds containing six chlorine atoms (Figure 10).

100. Exposure of *M. edulis* to 0-percent BRH (100-percent REF) sediment in Experiments 1 and 2 resulted in a change from the day 0 pattern to one showing a relatively greater abundance of lower molecular weight PCBs containing four and five chlorine atoms (Figure 11). The tentative identifications of peaks in these chromatograms are shown in Table 4.

101. PCB patterns in *M. edulis* exposed in the 30- and 10-percent BRH treatments for 14 or 28 days were similar to those from the 14-day exposure to 100- or 50-percent BRH material. These patterns showed a slightly greater abundance of low molecular weight PCB compounds and consistent changes in the relative height of some PCB peaks when compared with patterns in the 0-percent BRH (100-percent REF) exposed organisms.

Table 11
Chemical Analysis of Seawater in Exposure Chambers of 42-Day
Suspended Sediment Exposure Experiment to *N. incisa*

Experiment Day	Treatment % BRH	Total PCB (ng/l as Al254)	Total Metals µg/l		
			Cu	Cd	Cr
3	100	NS*	407	5.4	245
	50	NS	256	3.2	159
	0	NS	15	0.1	15
6	100	1,170	NS	NS	NS
	50	590	NS	NS	NS
	0	79	NS	NS	NS
18**	100	340	307	3.6	181
	50	510	208	3.5	125
	0	700	134	2.2	89
32	100	NS	357	5.0	203
	50		171	2.6	106
	0		15	0.1	16
42	100	1,920	NS	NS	NS
	50	980	NS	NS	NS
	0	12	NS	NS	NS

* Not sampled.

** Dosing system malfunctioned for 2 days spilling BRH sediments into all treatments.

102. *Mytilus edulis* exposed to REF suspensions showed peak patterns where the height of Peak 24 < Peak 26, Peak 36 > Peak 37, and Peak 41 > Peak 43 (Figure 11), a relationship that characterizes the background pattern. *Mytilus edulis* exposed to concentrations of BRH material in laboratory Experiments 1 and 2 showed patterns where the height of Peak 24 > Peak 26, Peak 36 approximately equal to Peak 37, and Peak 41 < Peak 43 (Figure 11), the BRH exposed pattern.

103. PCB concentrations. Results of Experiment 1 indicated that PCB tissue residues in *M. edulis* from the 50-percent BRH treatment were about half those from the 100-percent BRH treatment at day 14 (Table 12). This indicates that uptake is directly related to exposure concentration. PCB concentrations in *M. edulis* from the 0-percent BRH treatment (100-percent REF) remained about the same over the 14-day experiment.

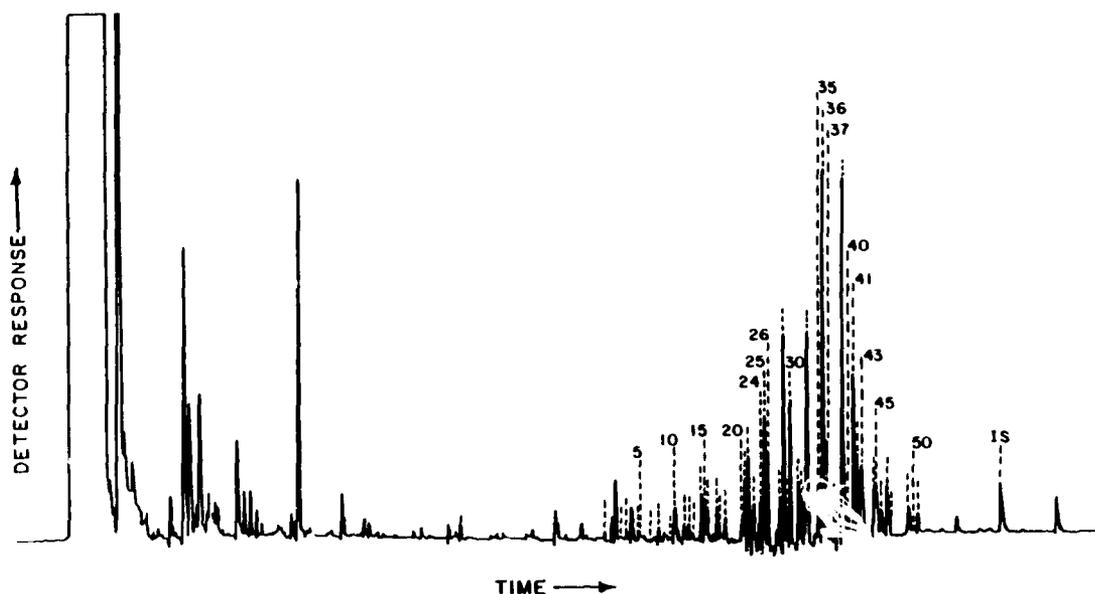
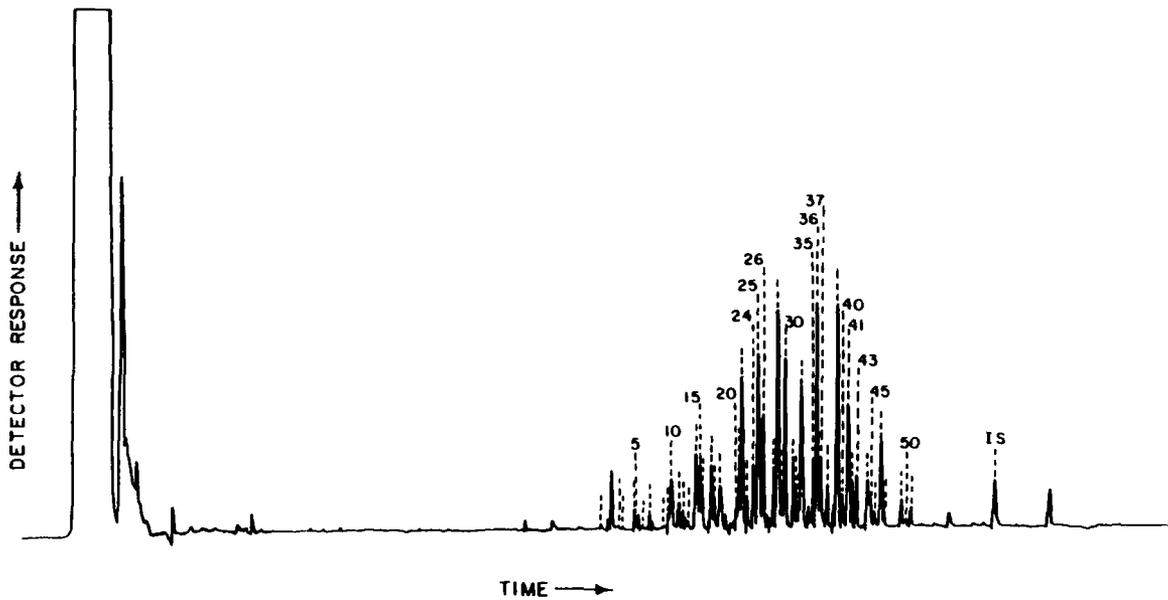


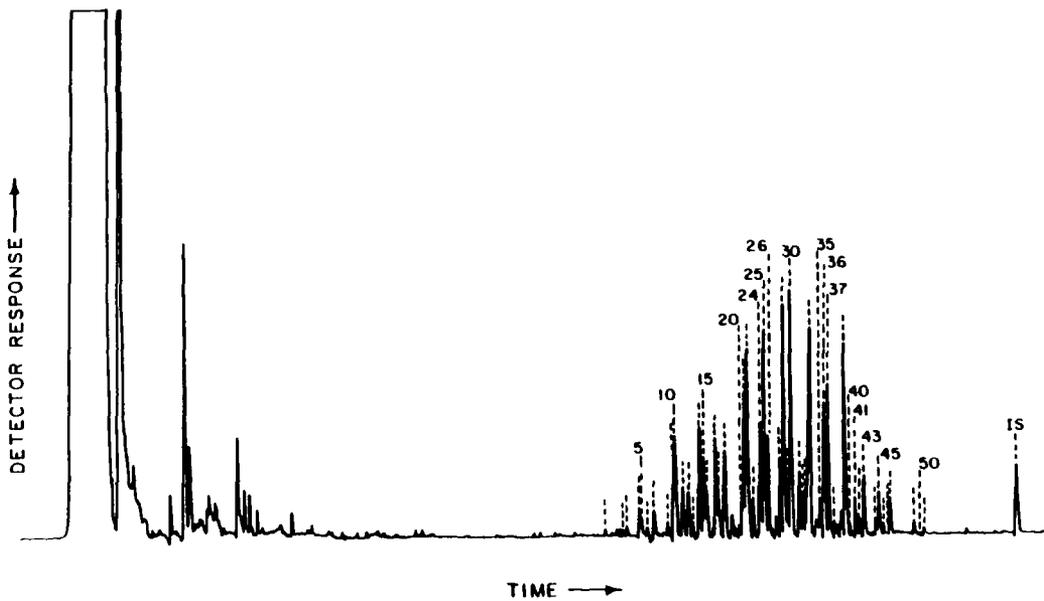
Figure 10. Capillary column electron capture gas chromatogram of fraction containing PCBs from day 0 *M. edulis* used in laboratory studies

104. The PCB residue data from Experiment 2 are graphically depicted in Figure 12. Tissue residues, measured at 7-day intervals, indicated that the *M. edulis* in the 0-percent BRH chamber maintained a relatively constant background concentration of PCBs throughout the experiment. In the 10- and 30-percent BRH chambers, the concentration of PCBs in the *M. edulis* increased between days 0 and 14, then remained nearly constant between days 14 and 28, suggesting that steady-state PCB concentrations were reached sometimes between days 7 and 14. The steady-state PCB concentration in *M. edulis* in the 30-percent BRH treatment was almost double that of *M. edulis* from the 10-percent BRH treatment. The actual concentration of BRH in the 30-percent BRH treatment, 3.3 mg/l, was nearly double that in the 10-percent BRH treatment, 1.5 mg/l. The measured whole water concentrations of PCB were 12 and 24 ng/l for the 10- and 30-percent BRH treatments, respectively. These data indicated a good relationship between the actual exposure concentrations of BRH suspended sediment, the measured PCB whole water concentrations, and the PCB tissue residues in the *M. edulis* in Experiment 2.

105. A comparison of the tissue residues between the two experiments can be made for days 0 and 14. The PCB concentrations in the day 0 *M. edulis* from Experiment 1 were slightly more than half of those from Experiment 2



a. 0% BRH



b. 30% BRH

Figure 11. Capillary column electron capture gas chromatograms of fraction containing PCBs from 0-percent BRH exposed *M. edulis* and 30-percent BRH exposed *M. edulis* from laboratory studies

Table 12
PCB Tissue Residues (ng/g dry weight) in *M. edulis* from the
First Laboratory Experiment

Day	% BRH		
	0	50	100
0	117	117	117
14	154	2,100	3,700

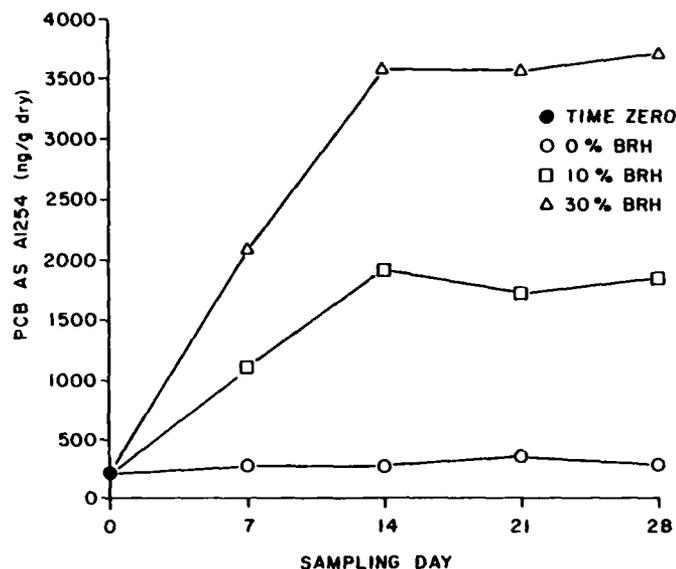


Figure 12. Concentrations of PCB as A1254 in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

(117 and 210 ng/g, respectively). In addition, day 14 PCB concentrations were about the same for the 10- and 50-percent BRH exposed mussels (1,910 and 2,100 ng/g, respectively) as well as the 30- and 100-percent BRH exposed mussels (3,600 and 3,700 ng/g, respectively). These data show exposure responses within each experiment; however, there is poor agreement between experiments. The PCB data from these experiments were normalized to nanograms per gram of lipid and the results presented in Table 13. Inspection of these data show that differences between experiments can be explained when differences in lipid content of the organisms are taken into account. In addition, this procedure indicates that an exposure-residue relationship exists between experiments when the day 14 data from both experiments are combined (Figure 13).

Table 13
PCB Concentrations (ng/g lipid) in *M. edulis*
from Both Laboratory Experiments

Day	% BRH Treatments					
	0*	0**	10**	30**	50*	100*
0	2,900	2,400	2,400	2,400	2,900	2,900
7	--†	5,200	17,100	24,000	--	--
14	3,800	4,300	27,000	54,000	53,000	119,000
21	--	5,000	35,000	67,000	--	--
28	--	3,800	30,000	66,000	--	--

* Experiment 1.
 ** Experiment 2.
 † Not sampled.

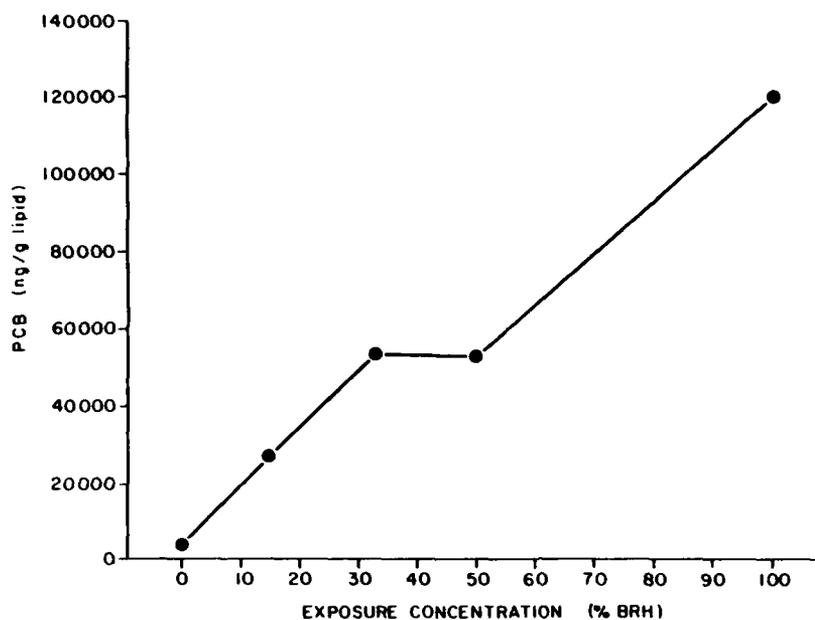


Figure 13. Concentrations of PCB as A1254, normalized for lipids, in the tissue of *M. edulis* exposed to BRH sediment for 14 days

106. PAH and ethylan patterns. The tissue residues in *M. edulis* from Experiments 1 and 2 show similar patterns of PAHs and ethylan. Identities of compounds represented by the bars are shown in Table 5. The pattern of PAHs in the day 0 *M. edulis* from Experiment 2 shows a dominance of the nonalkylated PAH compounds phenanthrene and fluoranthene (Figure 14). Ethylan was not found in these *M. edulis*. After 14 days exposure (Experiment 1) or 28 days

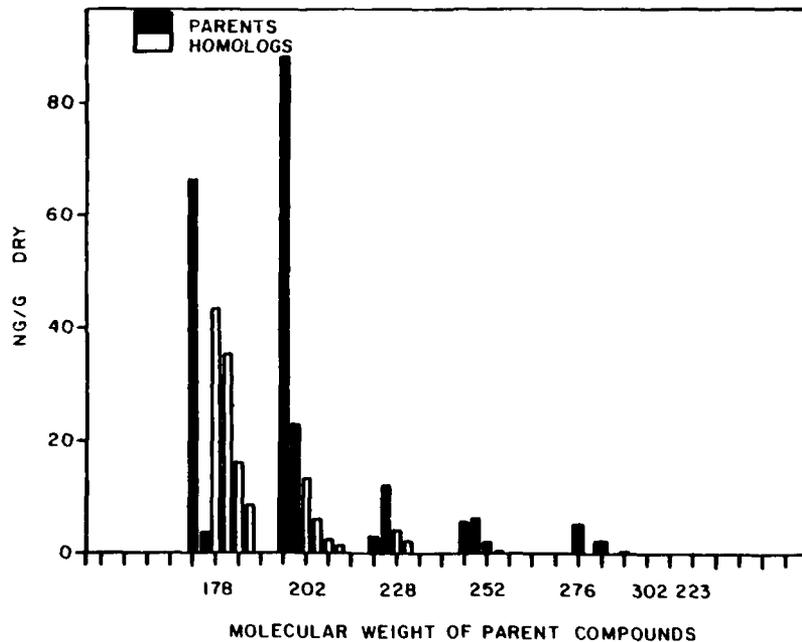
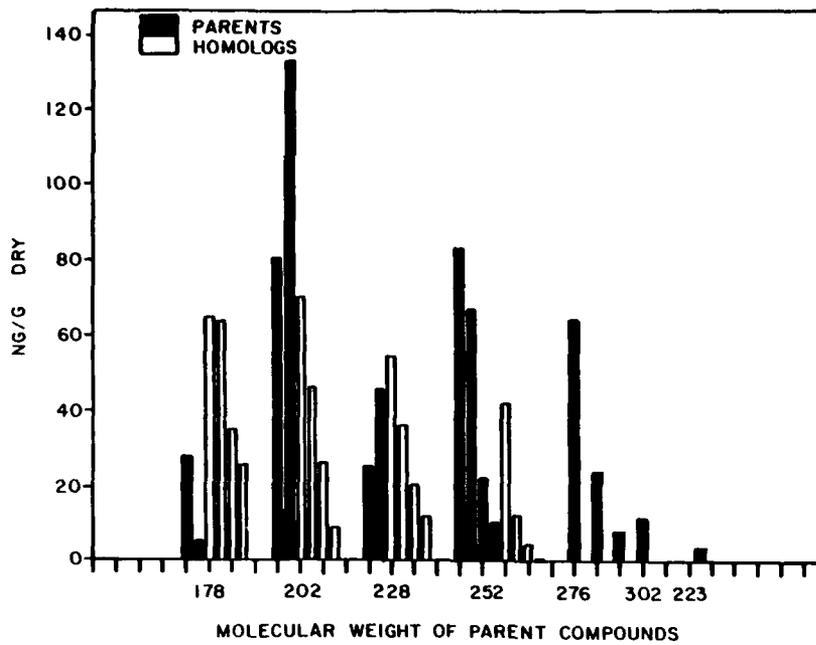


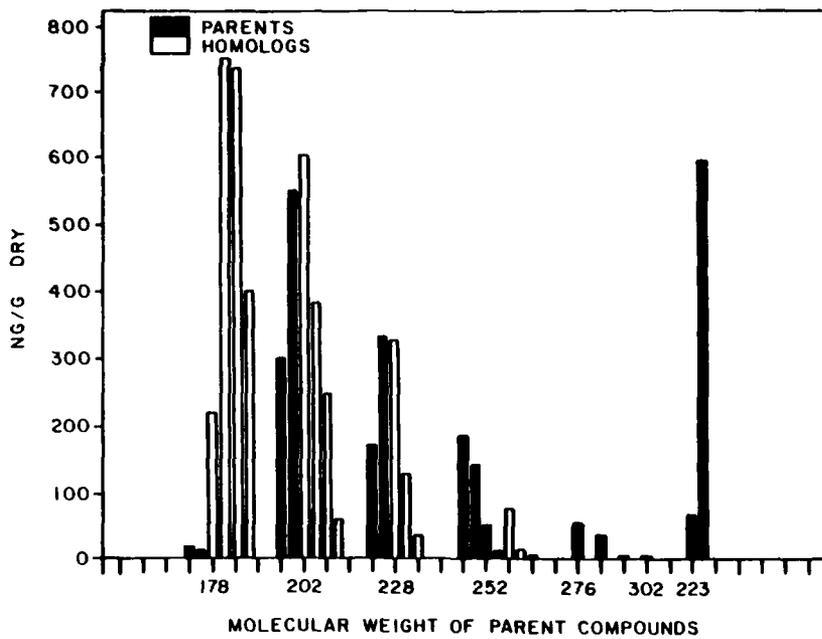
Figure 14. Bar graph of PAHs and ethylan in the tissue of day 0 *M. edulis* from laboratory exposures (Experiment 2)

exposure (Experiment 2) to 0-percent BRH (100-percent REF) suspended sediment, the distributions in *M. edulis* showed a greater relative abundance of higher molecular weight PAHs than in the day 0 organisms (Figure 15). In addition, the alkyl homologs of the molecular weight 178 and 202 PAH compounds were more prominent. Only a trace of ethylan is evident in these patterns. The patterns in *M. edulis* after exposure to 10-, 30-, 50-, or 100-percent BRH suspended sediments were similar for both Experiments 1 and 2, and when compared with patterns from organisms exposed to 0-percent BRH, showed the alkylated homologs of the molecular weight 178 PAHs to be dominant, and the alkyl homologs of molecular weight 202 and 228 PAHs to be relatively abundant as was ethylan (Figure 15).

107. PAH and ethylan concentrations. The changes in the concentration of phenanthrene, the sum of alkyl homologs of the 178 PAHs, fluoranthene, benzo(a)pyrene, ethylan, CENT, and SUM over the temporal span of Experiment 2 are shown in Figures 16-19. In general, the concentration of these variables in *M. edulis* exposed to BRH material showed a rapid increase during the first 7 to 14 days followed by a leveling or decrease of concentrations through the remainder of the experiment. The concentration of the SUM was 15 to 20 times higher in *M. edulis* exposed to 30- and 10-percent BRH sediments than in the

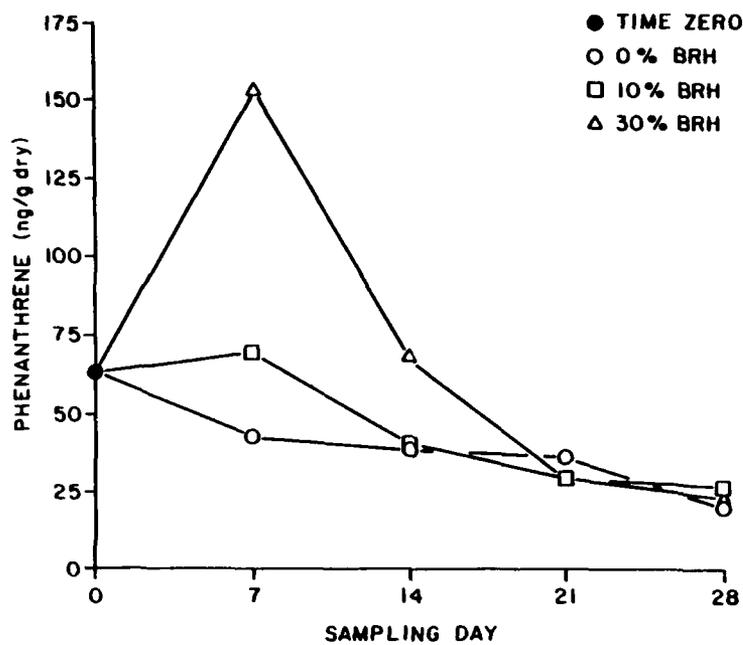


a. 0% BRH

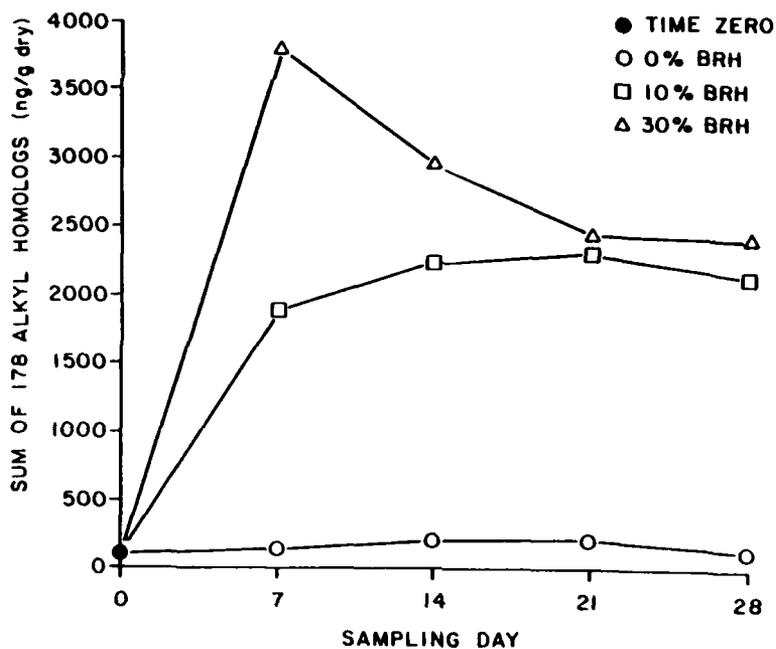


b. 30% BRH

Figure 15. Bar graphs of PAHs and ethylan in the tissue of *M. edulis* exposed to 0- and 30-percent BRH suspended sediments for 28 days

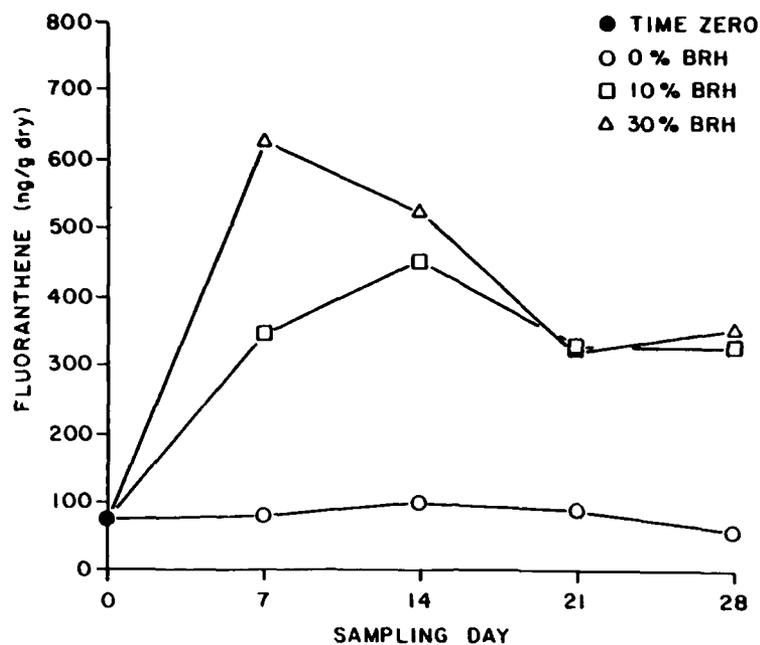


a. Phenanthrene

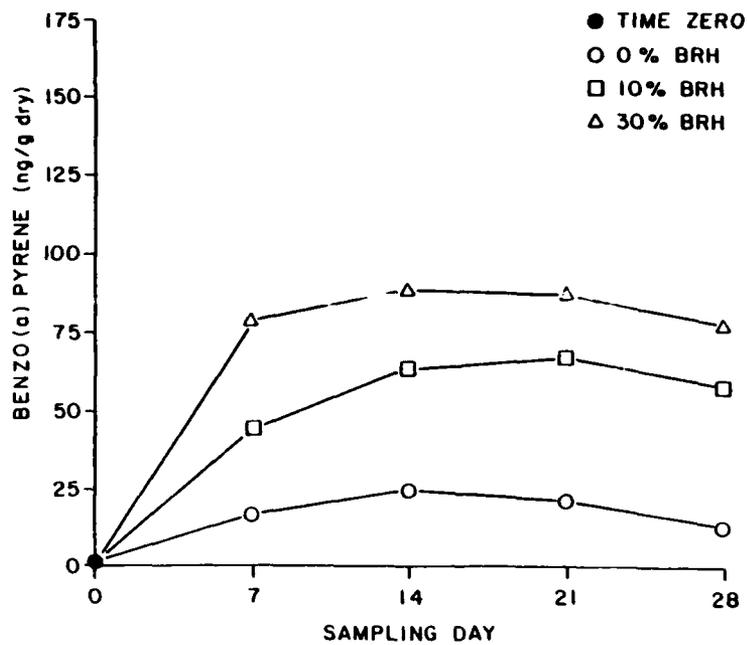


b. Sum of 178 homologs

Figure 16. Concentrations of phenanthrene and sum of 178 alkyl homologs in the tissues of *M. edulis* exposed to BRH suspended sediments for 28 days

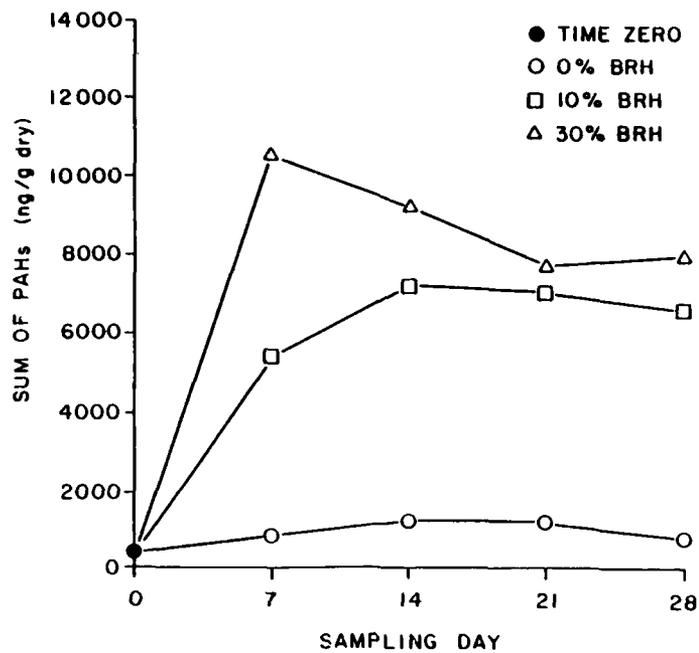


a. Fluoranthene

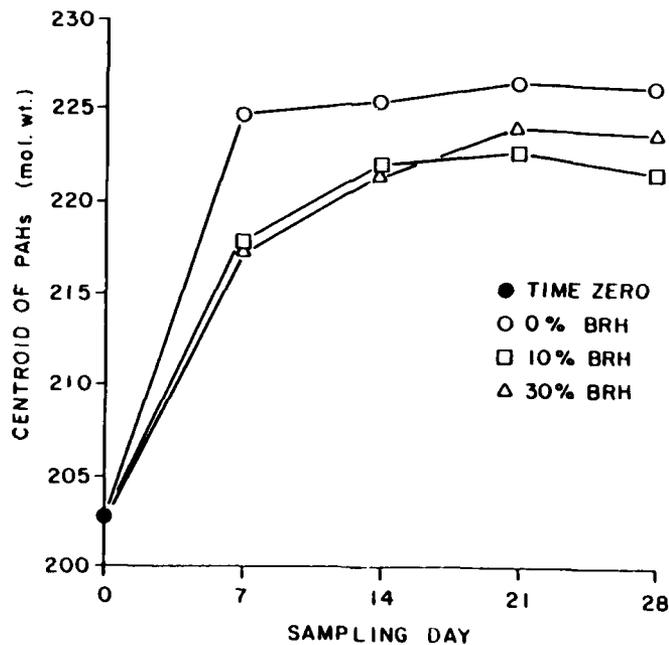


b. Benzo(a)pyrene

Figure 17. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days



a. SUM of PAHs



b. CENT of PAHs

Figure 18. Concentrations of the SUM of PAHs and CENT of PAHs in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

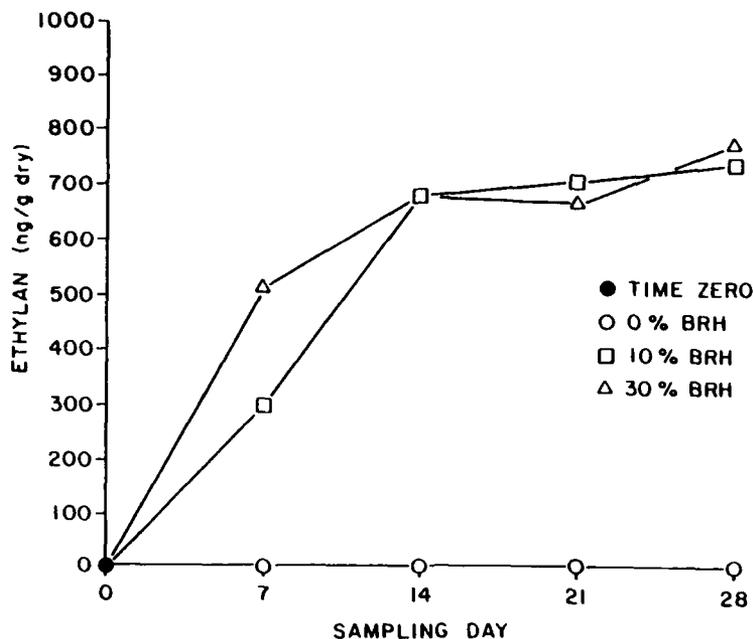


Figure 19. Concentrations of ethylan in the tissue of *M. edulis* exposed to BRH suspended sediment for 28 days

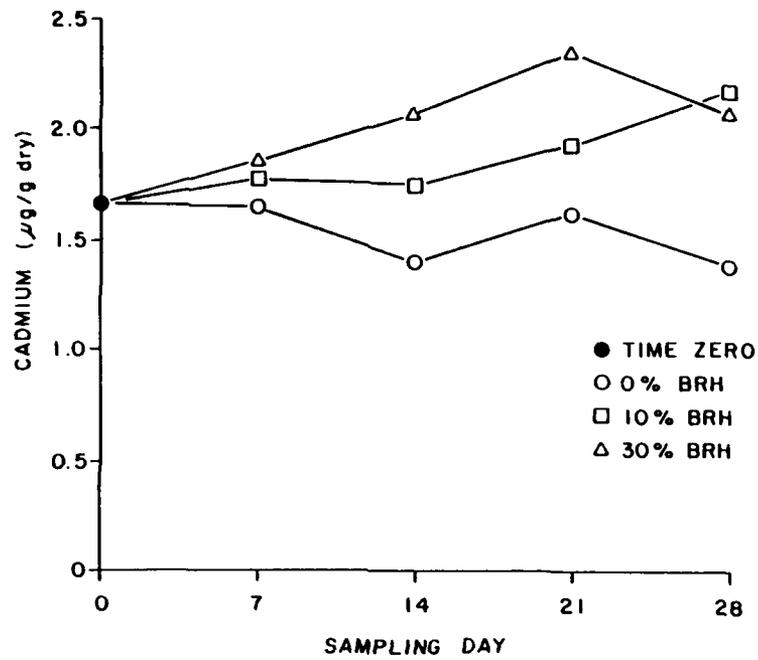
reference organisms (100-percent REF) at day 28. CENT showed a shift to higher molecular weight during this study.

108. Metals. Of the metals examined in Experiment 2, only copper showed relatively large residue concentration increases after a 28-day exposure to BRH sediment mixtures (Figures 20 and 21). The increases in copper concentration at day 28 in *M. edulis* were from 7 times (10-percent BRH exposure) to 13 times (30-percent BRH exposure) above reference values. All exposures were at 10 mg/l suspended solids. The maximum concentration increases observed for chromium, cadmium, and iron in *M. edulis* from these BRH exposures were less than 2 times above reference values. The variations in chromium and iron concentrations in *M. edulis* probably reflect natural variability in the organisms and do not represent bioaccumulation.

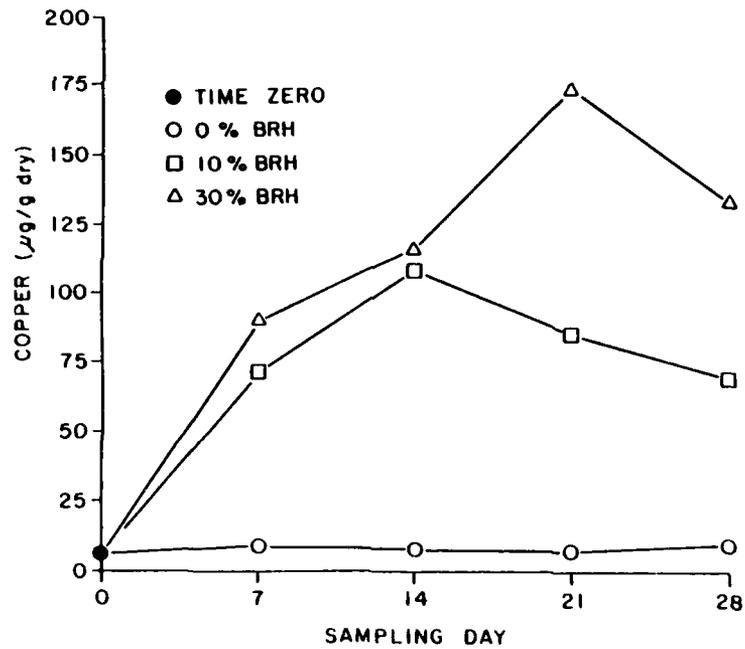
Tissue residue - *Nephtys incisa*

109. PCB patterns. The distribution and patterns of PCBs present in day 0 *N. incisa* were almost identical to those of *N. incisa* exposed to either bedded or suspended REF sediment. The distribution in these organisms ranged from Cl₃ to Cl₁₀ PCBs with the Cl₆ PCBs dominant (Figure 22).

110. Exposure to BRH sediments resulted in changes to the patterns in these organisms. *Nephtys incisa* bedded exposures resulted in a relatively

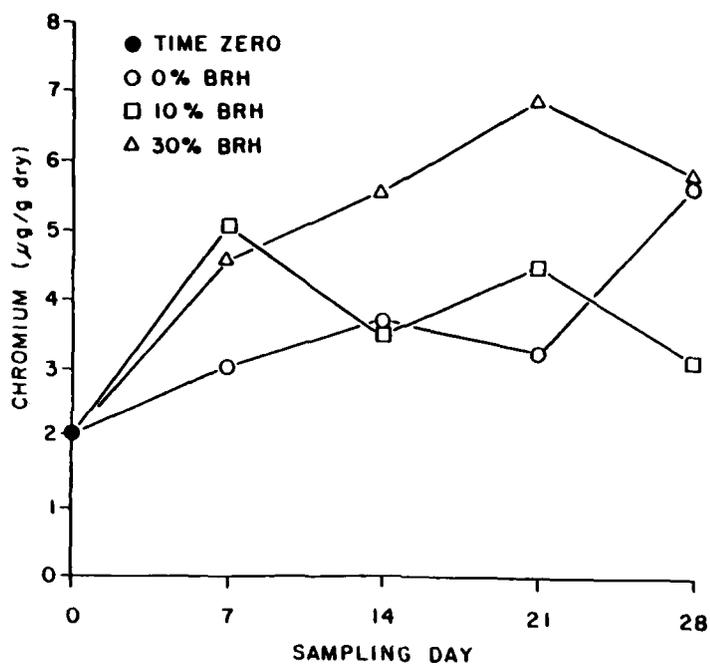


a. Cadmium

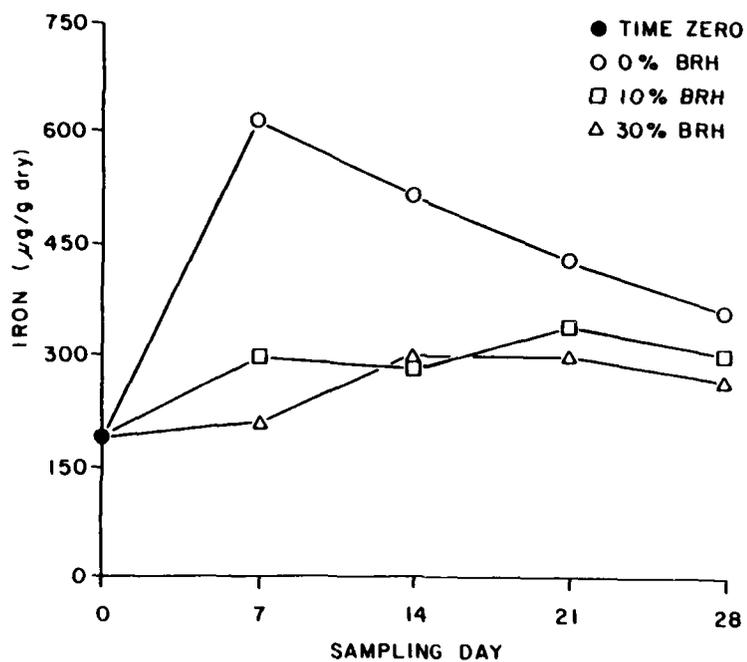


b. Copper

Figure 20. Concentrations of cadmium and copper in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days

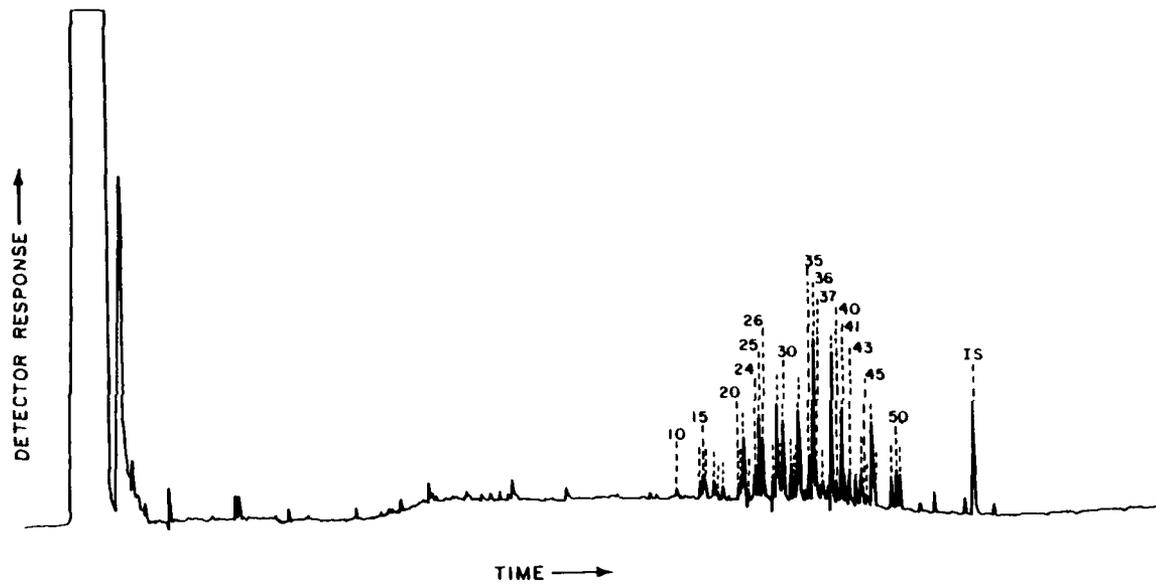


a. Chromium

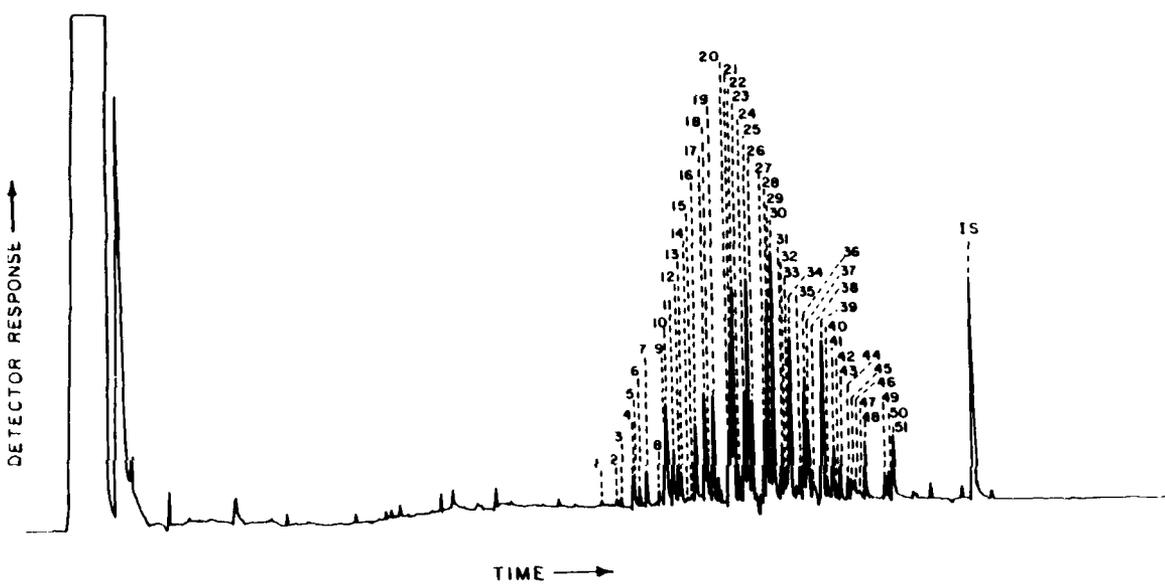


b. Iron

Figure 21. Concentrations of chromium and iron in the tissue of *M. edulis* exposed to BRH suspended sediments for 28 days



a. Day 0



b. Day 28

Figure 22. Capillary column electron capture gas chromatograms of the PCB fraction from the tissue of day 0 *N. incisa* used in laboratory exposures and *N. incisa* exposed to BRH bedded sediment for 28 days

greater abundance of Cl₃ and Cl₄ PCBs at day 10 for both BRH treatment levels. By day 28 the patterns had changed and the Cl₅ and Cl₆ PCBs dominated (Figure 22). The patterns in *N. incisa* from day 28 bedded and day 42 suspended exposure to BRH sediment were similar. Comparison of these patterns with those from *N. incisa* exposed to REF shows that changes in the ratios of several peak heights resulted from exposure to either bedded or suspended BRH sediment. Day 0 *N. incisa* and those exposed to REF showed ratios of peak heights with Peak 24 < Peak 26, Peak 36 > Peak 37, and Peak 41 > Peak 43. Exposure to BRH sediments for 28 days or more resulted in the ratios of peak heights changing to Peak 24 > Peak 26, Peak 36 approximately equal to Peak 37, and Peak 41 < Peak 43. The patterns in BRH exposed organisms also showed a greater relative abundance of lower molecular weight compounds than the *N. incisa* from the REF exposure.

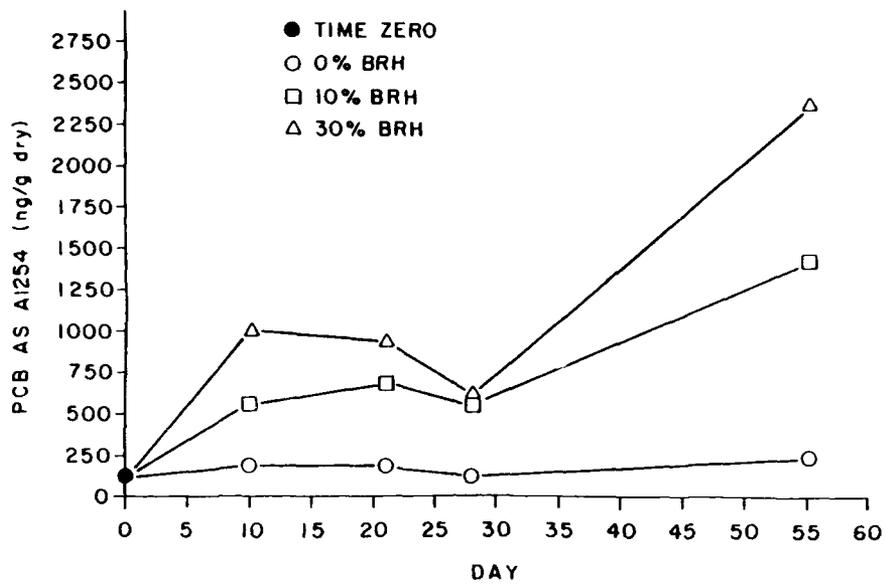
111. PCB concentrations. The uptake of PCBs by *N. incisa* from the bedded sediment exposures is shown in Figure 23. The concentration of PCBs in *N. incisa* increased upon exposure for 10 days to the 10-percent or the 30-percent BRH sediment mixtures, and then leveled out (or decreased slightly) from day 10 to day 28. The day 55 *N. incisa* samples showed higher concentrations of PCBs than the day 28 samples for both treatments. The concentrations of lipids in the organisms from the bedded sediment study did not pass internal quality assurance checks and could not be used.

112. *Nephtys incisa* exposed to 50- and 100-percent suspended BRH sediment for 28 days showed increased tissue residue concentrations of PCBs which leveled out between day 28 and day 42 for the 50-percent BRH treatment, but continued to rise for the 100-percent BRH treatment. The PCB concentration in *N. incisa* from the REF (0-percent BRH) exposures from both the bedded and the suspended exposure experiments did not change appreciably.

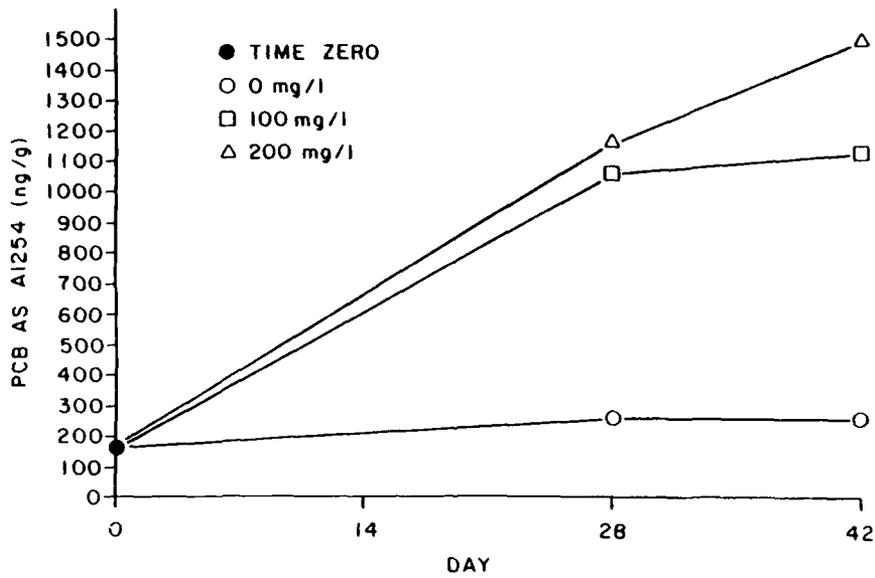
113. An exposure-residue relationship (increased BRH exposure resulting in increased PCB residues in *N. incisa*) can be observed within each study, but a comparison between studies is precluded due to the different exposure modes.

114. PAH and ethylan patterns. The patterns of PAHs in day 0 *N. incisa* used in both the bedded sediment and the suspended sediment exposures were similar (Figure 24). Ethylan was not found in these samples.

115. During the bedded sediment experiment, a relative decrease in the amount of molecular weight 178 parent and homologs was found in *N. incisa* exposed to REF sediment. Similar changes were not found in *N. incisa* exposed



a. Bedded sediment



b. Suspended sediment

Figure 23. Concentrations of PCB as A1254 in the tissue of *N. incisa* exposed to BRH bedded sediment for 55 days and BRH suspended sediment for 42 days

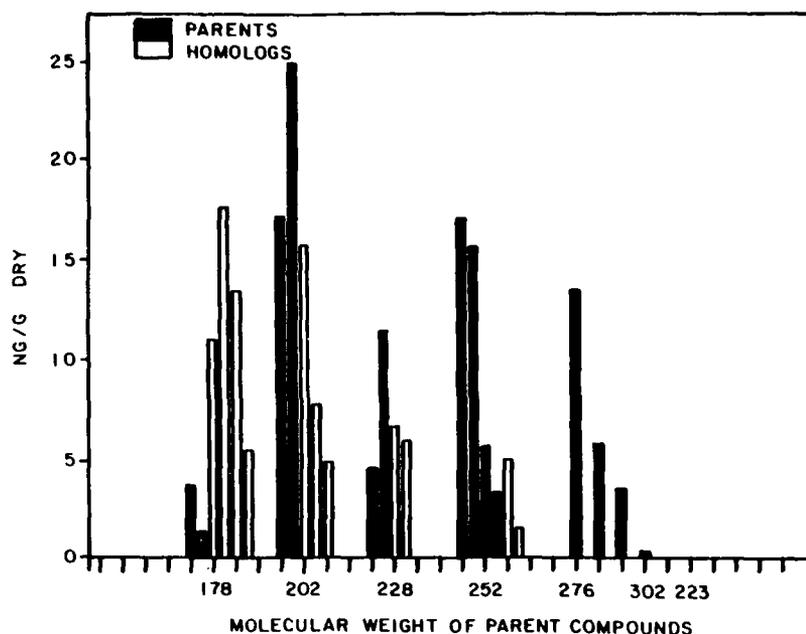


Figure 24. Bar graph of PAHs and ethylan in the tissue of day 0 *N. incisa* used in laboratory bedded sediment exposures

to suspended REF sediment. Ethylan was not found in these samples.

116. *Nephtys incisa* exposed to 10- or 30-percent BRH bedded sediments showed a relative increase in 178 and 202 PAH parents and homologs, and ethylan was present at day 10 (Figure 25). During the remainder of the experiment, a relative decrease in the abundance of the parent 178 compounds was noticed, but other pattern changes were small. *Nephtys incisa* exposed to 50- or 100-percent BRH suspended sediments showed a relative increase in 178 and 202 parents and homologs and the presence of ethylan at day 42.

117. The relative increases in the 178 and 202 parents and homologs observed in the PAH patterns were also found as decreases in CENT (Figure 26), and the decreases in CENT were greater for the bedded than for the suspended exposure. The reason(s) for the difference in the initial value of CENT for the two studies is unknown, but may reflect natural variability.

118. PAH and ethylan concentrations. Changes in the concentration of PAHs and ethylan in *N. incisa* during the bedded sediment study are shown in Figures 27-29. In general, compounds showed an exposure-residue relationship in which highest exposure resulted in the highest residue concentrations. For most of these compounds, the concentration at day 10 was highest, followed by

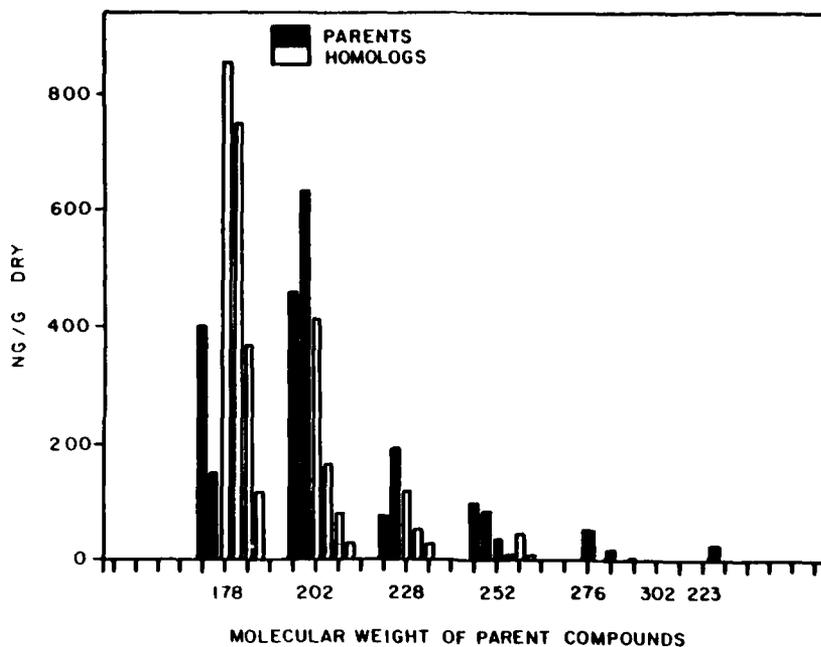
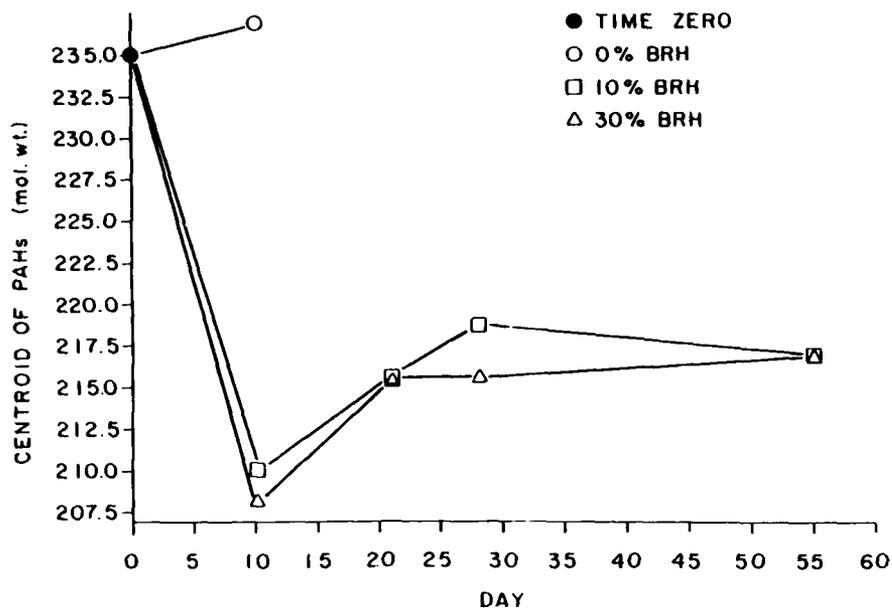


Figure 25. Bar graph of PAHs and ethylan in the tissue of *N. incisa* exposed to 10-percent BRH bedded sediment for 10 days

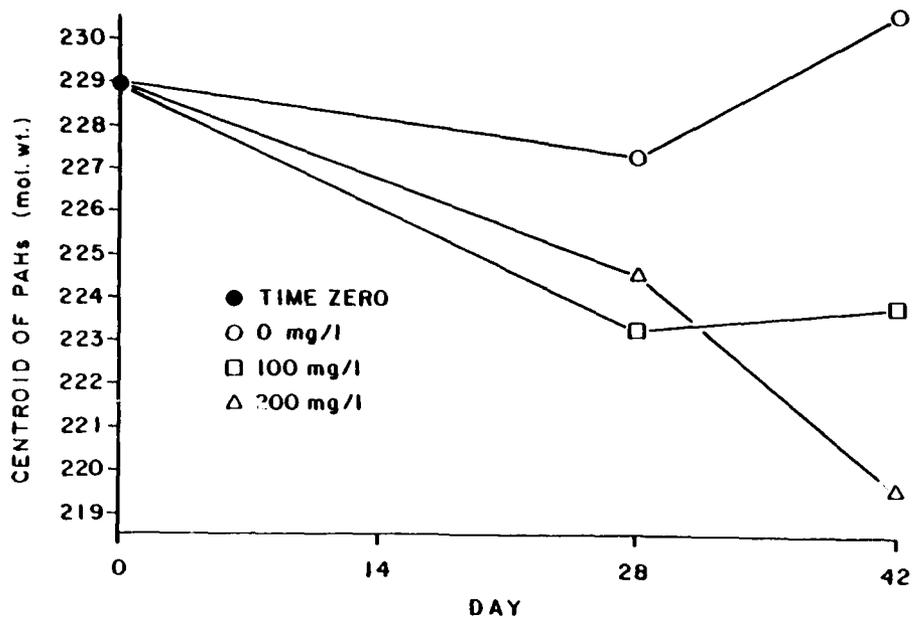
a decrease and/or leveling trend through the remainder of the study. However, benzo[a]pyrene appeared to increase in concentration throughout the study.

119. Changes in the concentrations of PAHs and ethylan in *N. incisa* during the suspended sediment study are shown in Figures 30-32. By day 28 the concentrations had increased. At day 42 the concentrations in *N. incisa* from the 50-percent BRH treatment had increased relative to day 28 values, but the concentration in *N. incisa* from the 100-percent BRH treatment tended to plateau (homologs of 178s, ethylan) or decrease (SUM, 178 parents, benzo[a]pyrene). The 202 parent PAHs showed small increases from day 28 to day 42.

120. Metals. Exposure to 50- and 100-percent BRH suspended sediments (200 mg/l) resulted in the accumulation of cadmium and copper (Figure 33). The other metals examined showed no apparent accumulation trends in either the suspended or bedded exposure laboratory studies.

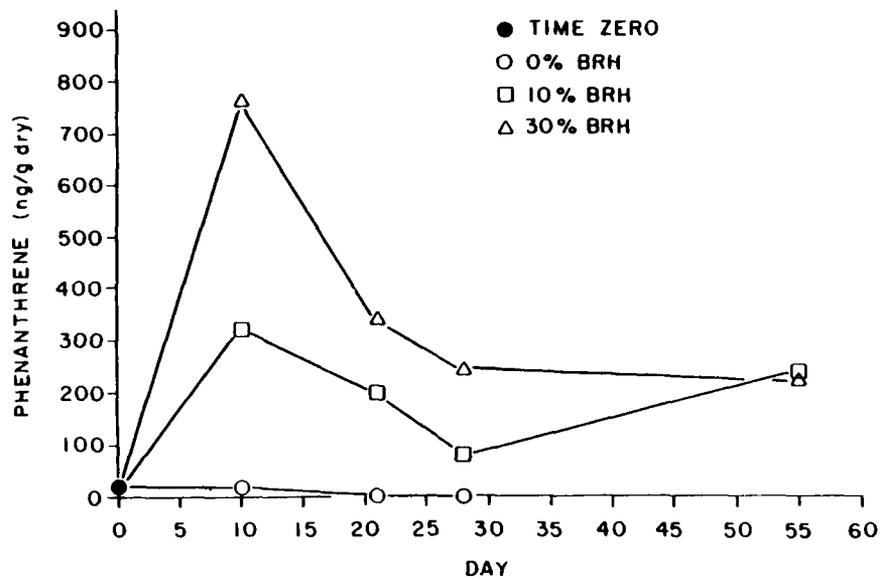


a. Bedded sediment

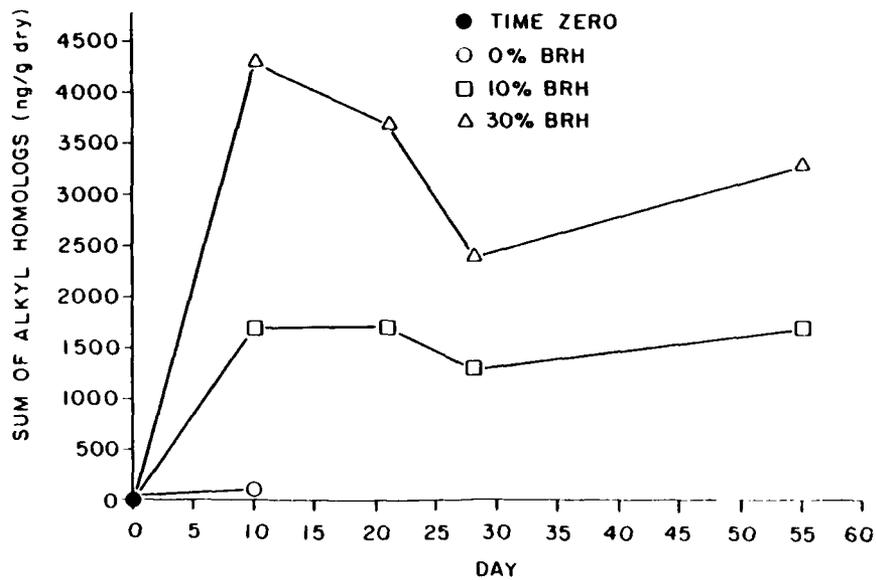


b. Suspended sediment

Figure 26. CENT of PAHs in the tissue of *N. incisa* exposed to BRH bedded sediment for 55 days and BRH suspended sediment for 42 days

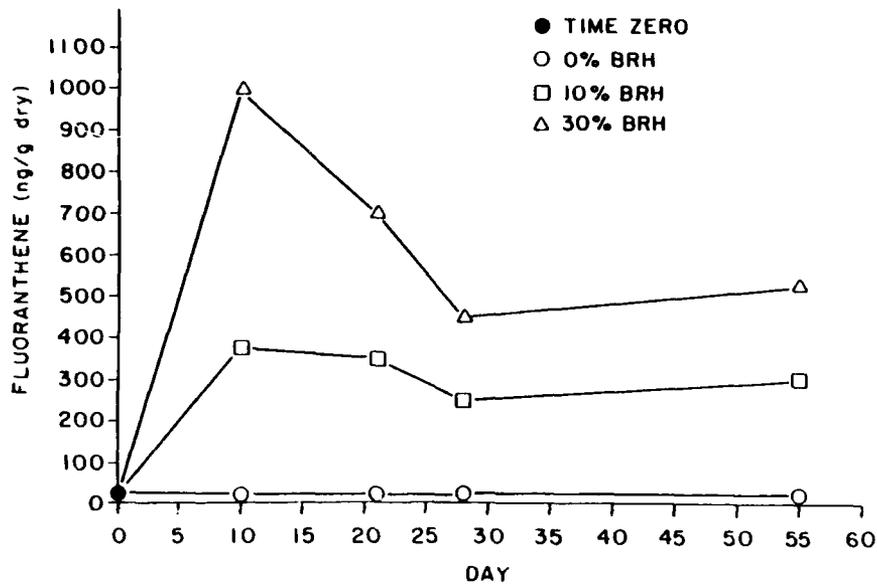


a. Phenanthrene

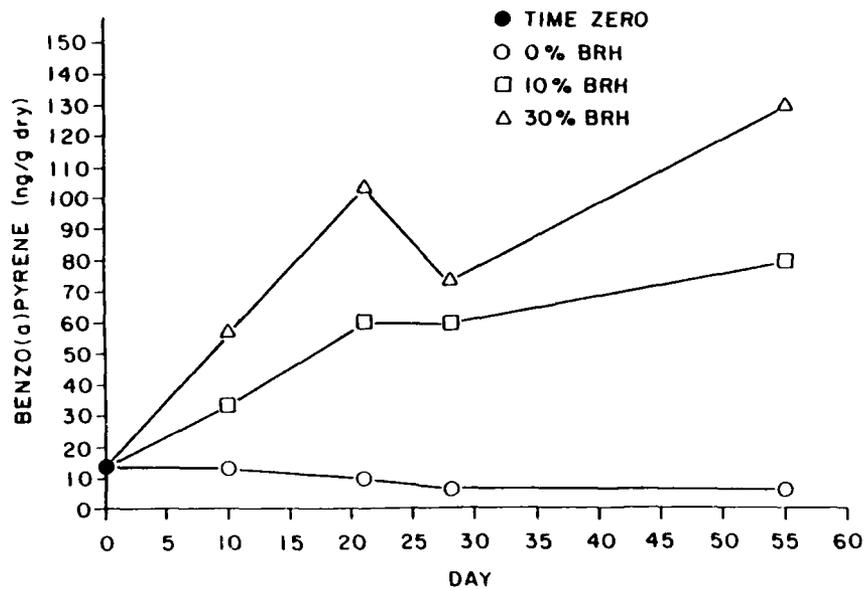


b. Sum of 178 alkyl homologs

Figure 27. Concentrations of phenanthrene and sum of 178 alkyl homologs in the tissue of *N. incisa* exposed to BRH bedded sediment for 55 days

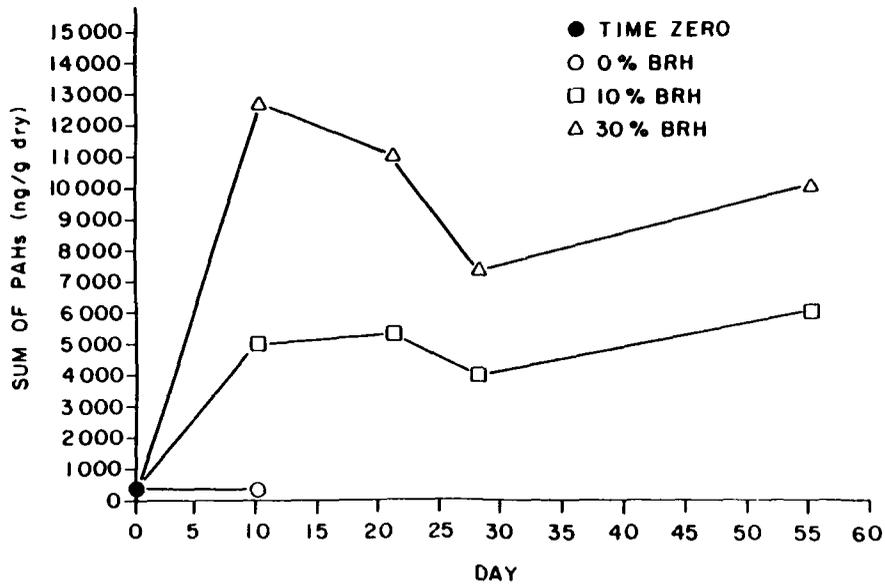


a. Fluoranthene

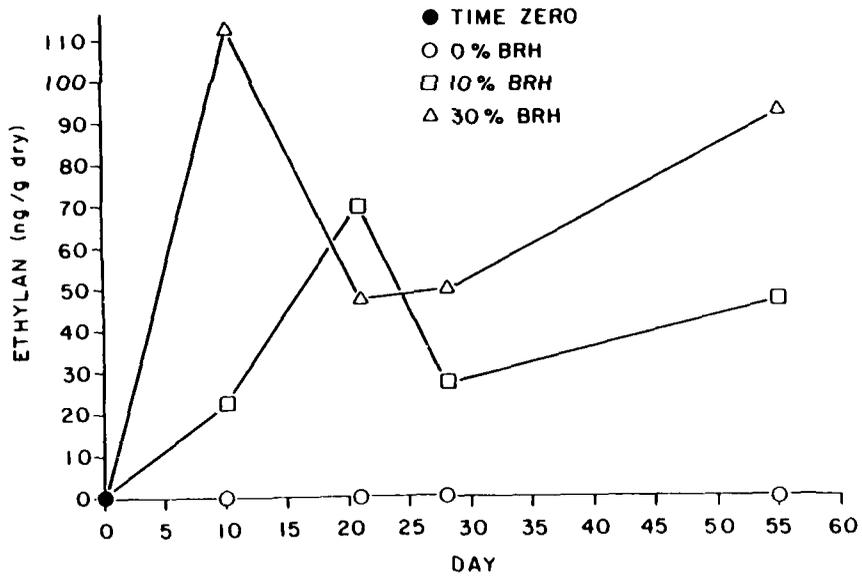


b. Benzo(a)pyrene

Figure 28. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *N. incisa* exposed to BRH bedded sediment for 55 days

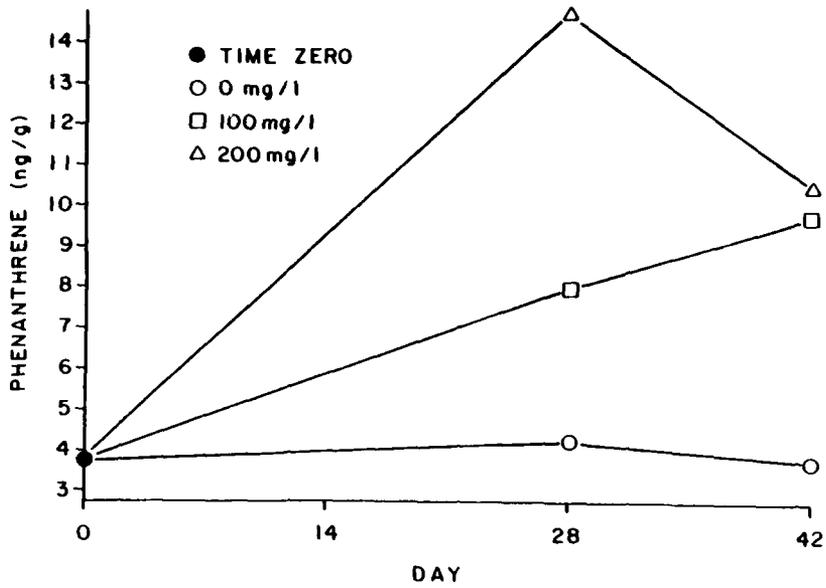


a. SUM of PAHs

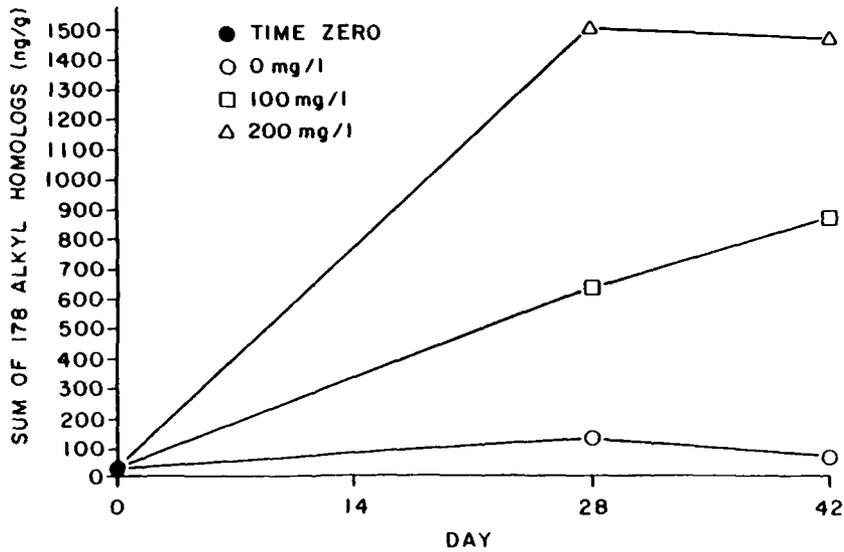


b. Ethylan

Figure 29. Concentrations of SUM of the PAHs and ethylan in the tissue of *N. incisa* exposed to BRH bedded sediment for 55 days

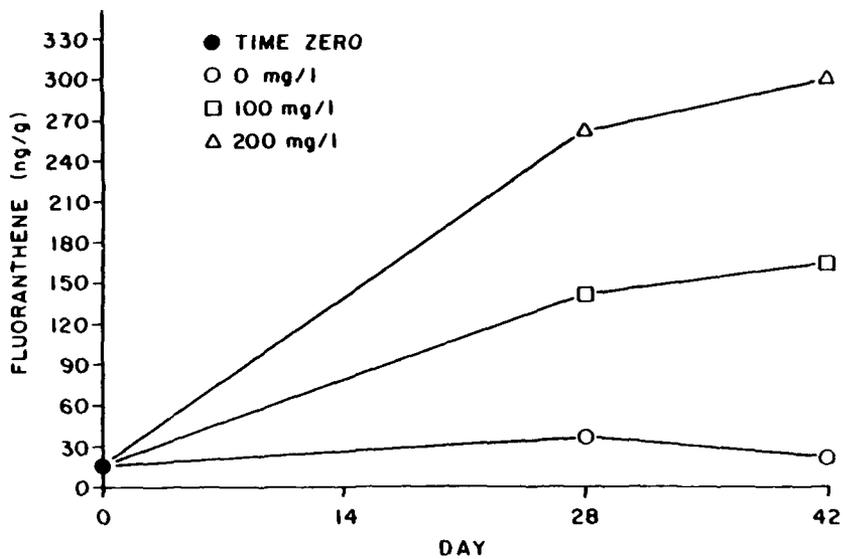


a. Phenanthrene

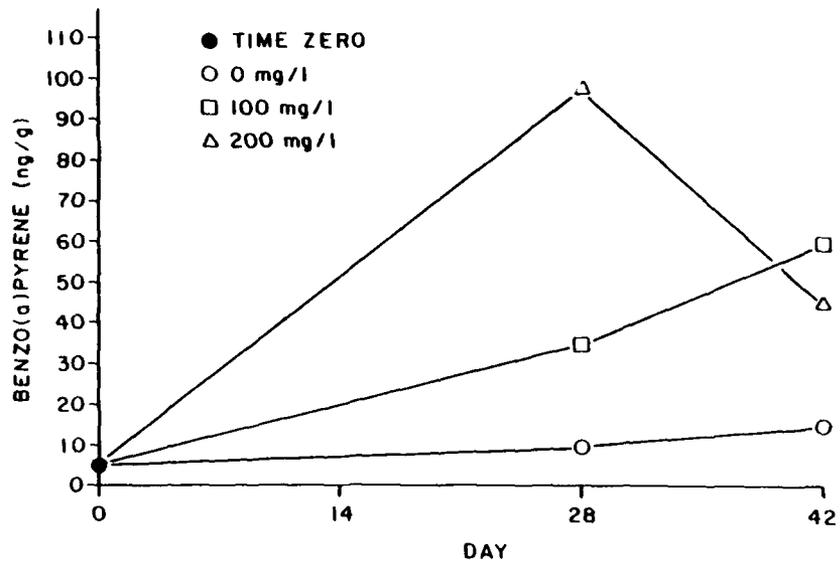


b. Sum of 178 alkyl homologs

Figure 30. Concentrations of phenanthrene and the sum of 178 alkyl homologs in the tissue of *N. incisa* exposed to BRH suspended sediment for 42 days

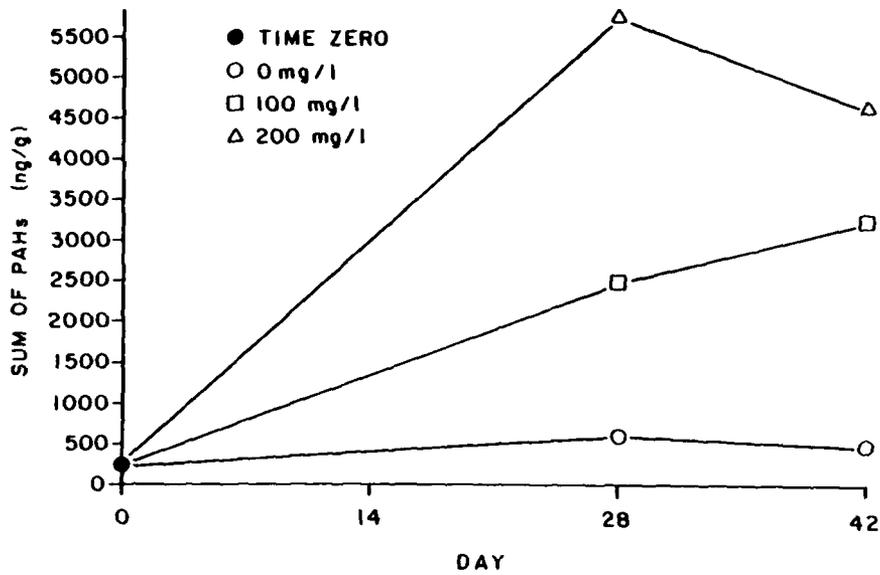


a. Fluoranthene

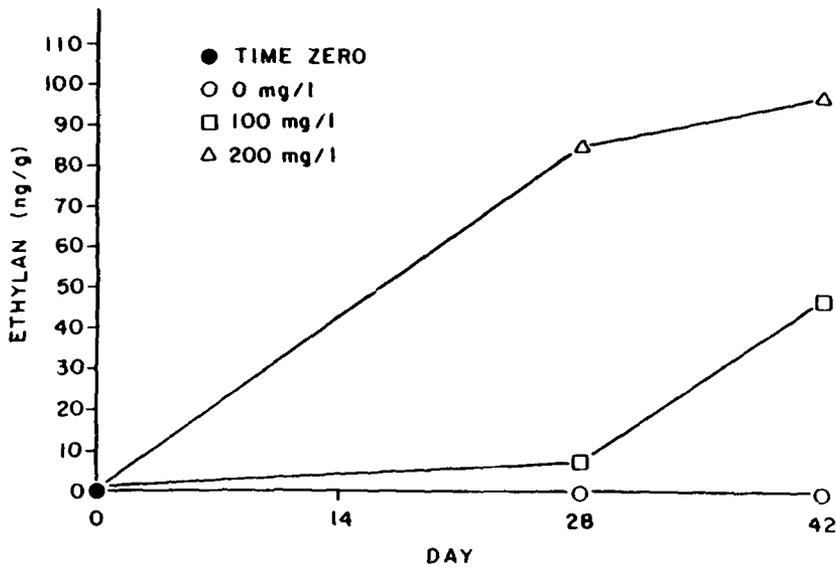


b. Benzo(a)pyrene

Figure 31. Concentrations of fluoranthene and benzo(a)pyrene in the tissue of *N. incisa* exposed to BRH suspended sediment for 42 days

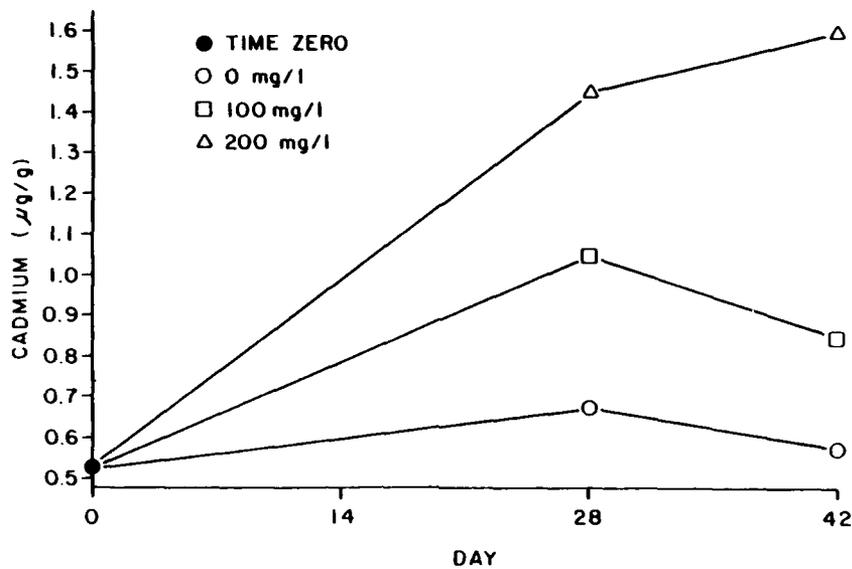


a. SUM of PAHs

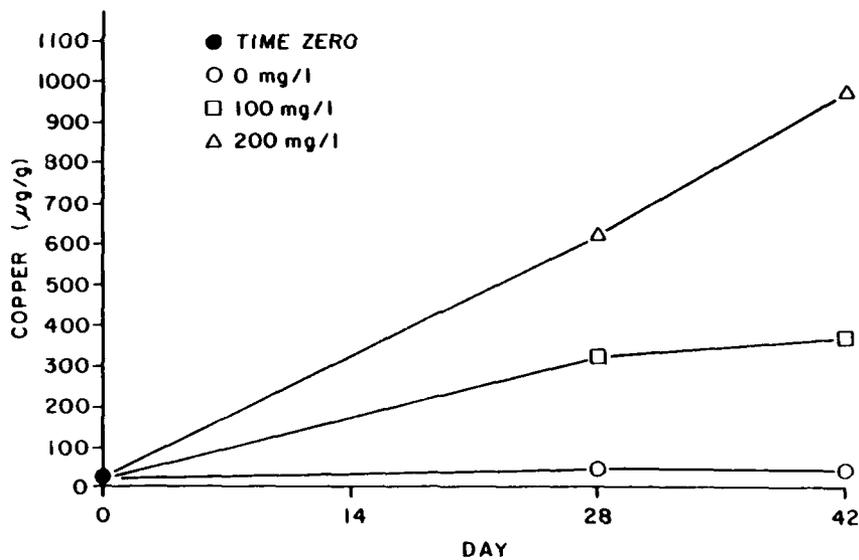


b. Ethylan

Figure 32. Concentrations of the SUM of the PAHs and ethylan in the tissue of *N. incisa* exposed to BRH suspended sediment for 42 days



a. Cadmium



b. Copper

Figure 33. Concentrations of cadmium and copper in the tissue of *N. incisa* exposed to BRH suspended sediment for 42 days

Field

Exposure - *Mytilus edulis*

121. Estimated from tissue residues. The first method used to determine possible exposure conditions of *M. edulis* to BRH material in CLIS involved the use of laboratory-generated relationships between PCB tissue residues and BRH exposures.

122. The predicted exposures for each station and collection date demonstrated several spatial and temporal trends (Table 14). Spatially, the data indicate a trend towards greater exposure near the CNTR station immediately following disposal. This is evidenced by the elevated exposures at T = 0 (1000E > REFS) and T + 2 (400E > 1000E > REFS) toward the disposal mound. This pattern disappeared by T + 8, when exposures were nearly the same at the CNTR, 400E, and 1000E stations, with the REFS station being lower than the other three.

123. Temporally, the estimated BRH exposures decreased with increasing time from disposal. The maximum exposure occurred at the 400E station at T + 2. This value ranged between 1.4 and 0.8 mg/l of BRH suspended sediment, depending on whether the background concentration at REFS was subtracted. By the next collection, T + 8, the maximum estimated exposure, also at 400E, decreased to between 0.7 and 0.3 mg/l, half that of the previous collection. Subsequent collections indicated a continued decrease to levels similar to those at the REFS station by T + 12.

124. Exposure estimated from water chemistry data. In addition to the estimates of BRH exposure based on mussel PCB tissue residues, a second estimate was made using PCB and copper concentrations in whole water samples taken postdisposal. The data indicate spatial and temporal trends similar to those obtained from the tissue residue estimate (Table 15).

125. Spatially, the sample collected on 7 June 1983 showed the highest BRH estimate (based on copper) at the CNTR station, followed by lower concentrations at 400E and 1000E stations, and the lowest levels at REFS. The estimate based on PCB concentrations indicated the CNTR station was elevated compared with the REFS station. The same pattern was observed in both the copper and PCB estimate for the 21 July 1983 sample. A decreasing concentration of BRH material was estimated moving away from CNTR.

126. On a temporal scale, the BRH concentration (copper data) decreased

Table 14

Predicted Range of BRH Suspended Sediment Exposures (mg/l)
Required To Achieve the Measured Tissue Residue
Values of Mussels Deployed in CLIS*

Collection Cruise	Station	Estimated Exposure Range	
		High Value	Low Value
T - 4	CNTR	0.37	0.00
	400E	0.26	0.00
	1000E	0.38	0.00
	REFS	0.43	0.00
T = 0	1000E	1.04	0.56
	REFS	0.49	
T + 2	400E	1.39	0.79
	1000E	0.98	0.38
	REFS	0.60	
T + 8	CNTR	0.67	0.21
	400E	0.71	0.25
	1000E	0.60	0.14
	REFS	0.46	
T + 12	CNTR	0.61	0.06
	400E	0.64	0.09
	1000E	0.53	0.00
	REFS	0.55	
T + 15	CNTR	0.84	0.31
	400E	0.61	0.08
	1000E	0.61	0.08
	REFS	0.53	
T + 21	CNTR	0.52	0.12
	400E	0.66	0.26
	1000E	0.55	0.15
	REFS	0.40	0.15
T + 27	400E	0.52	0.09
	1000E	0.37	0.00
	REFS	0.43	

(Continued)

* Each estimate was calculated based on laboratory-generated PCB residue-exposure concentration relationships. The high value was determined from the actual mussel tissue residue concentration while the low value was calculated after the REFS PCB residue was subtracted from the other stations during that collection period.

Table 14 (Concluded)

<u>Collection</u> <u>Cruise</u>	<u>Station</u>	<u>Estimated Exposure Range</u>	
		<u>High Value</u>	<u>Low Value</u>
T + 43	CNTR	0.33	0.06
	400E	0.31	0.04
	REFS	0.27	
T + 55	400E	0.52	0.00
	1000E	0.42	0.00
	1000E	0.47	0.00
	REFS	0.53	
T + 116	CNTR	0.30	0.00
	400E	0.34	0.00
	1000E	0.43	0.01
	REFS	0.42	

Table 15
Predicted BRH Suspended Sediment Exposure (mg/l) Based on PCB
 and Copper Whole Water Chemistry Data*

Date	Station	Estimate Using Copper		Estimate Using PCB	
		High	Low	High	Low
07 Jun 83 T + 2	CNTR	1.30	0.71	1.05	0.69
	400E	1.12	0.53	--	--
	1000E	1.14	0.55	--	--
	REFS	0.59	0.00	0.36	0.00
21 Jul 83 T + 9	CNTR	0.62	0.26	0.19	0.11
	400E	0.49	0.13	--	--
	1000E	0.41	0.05	--	--
	REFS	0.36	0.00	0.08	0.00
31 Aug 83 T + 15	CNTR	--	--	0.17	0.07
	400E	--	--	0.21	0.11
	1000E	--	--	0.16	0.06
	REFS	--	--	0.10	0.00
02 Sep 83 T + 15	CNTR	--	--	--	--
	400E	0.72	0.22	--	--
	1000E	--	--	--	--
	REFS	0.50	0.00	--	--
05 Dec 83 T + 27	CNTR	--	--	0.05	0.00
	400E	1.13	0.37	0.08	0.00
	1000E	--	--	0.09	0.00
	REFS	0.76	0.00	0.09	0.00
06 Jun 84 T + 55	CNTR	--	--	--	--
	400E	1.00	0.09	--	--
	1000E	--	--	--	--
	REFS	0.91	0.00	--	--

* Each estimate was calculated through division of the concentration of PCB or copper present in the field by the concentration of that material present in the BRH barrel material (6,910 ng/g and 2,900 µg/g for PCB and copper, respectively). The high value was determined from the actual whole water concentration while the low estimate was calculated after the REFS values were subtracted from the other stations during that collection period.

by about half from June to July (high value) based on the absolute copper levels at each location. Inspection of the low estimate indicated a more distinct pattern over the same time period. The BRH levels were highest immediately after the disposal operation (June 1983) and generally decreased with increasing time. The low estimate provided here is more a measure of relative difference between the stations, after background Long Island Sound concentrations are subtracted (REFS), and may be appropriate for discerning temporal trends.

127. The pattern of BRH exposure based on PCB water concentrations was very similar to that of copper. The highest value was detected at the CNTR station in June 1983 and decreased both spatially and temporally with increasing time. In addition, the high estimates did not show the same variability over time as the copper data. This may indicate that PCB concentrations in Long Island Sound were more constant over time and thus BRH estimates based on PCB concentrations were less influenced by background fluctuations.

Exposure - *Nephtys incisa*

128. Estimated from tissue residues. The first method used to estimate exposure conditions of *N. incisa* to BRH material in CLIS involved the laboratory-generated relationships between PCB tissue residues and BRH exposures. With this relationship, PCB tissue residues in field-collected *N. incisa* were used to estimate field BRH exposure concentrations.

129. One estimate of exposure of *N. incisa* to BRH sediment was made using the exposure-residue relationships for PCBs and SUM from laboratory bedded exposure studies. Initial attempts were made to combine data from the suspended exposure and the bedded exposure laboratory studies assuming that the exposure zone for the *N. incisa* in the suspended exposure studies was a layer of deposited sediment equivalent to the suspended dosage (i.e., 50-percent BRH in the suspended particulate matter (SPM) = 50-percent BRH exposure). This approach was abandoned because the correlation coefficient for the line relating percent BRH exposure to SUM fell from 0.975 to 0.444 when the suspended exposure data were included (Table 16). The exposure estimates made in Table 17 used only the bedded exposure data from the *N. incisa* laboratory studies and the measured tissue residues of PCBs and PAHs in *N. incisa* from the field. The highest exposures to BRH material were found for sediments near the mound up until T + 16. After T + 16 the estimates of exposure decreased.

Table 16
Concentration of Contaminants in *N. incisa* Versus Exposure Sediment
Used in Laboratory Studies

Exposure % BRH	Experiment	Sed Concentration, µg/g dry	<i>N. incisa</i> , µg/g dry at Day 28
<u>SUM</u>			
0	BE*	2.3 + 0.56 (n = 4)	0.40**
10	BE	6.8 + 1.2 (n = 4)	4.5 ± 1.6 (n = 2)
30	BE	19. + 4.8 (n = 4)	8.2 ± 2.3 (n = 2)
50	SE†	85.*	2.6 (n = 1)
100	SE	1.9 × 10 ^{2*}	6.3 (n = 1)
Using BE only		% BRH = (SUM × 3.82) - 3.4	R ² = 0.975
Using BE and SE		% BRH = (SUM × 5.76) + 12.6	R ² = 0.444
<u>PCBs (A1254)</u>			
0		0.034 + 0.0074 (n = 4)	0.14 + 0.03 (n = 2)
10		0.55 + 0.045 (n = 4)	0.55 + 0.06 (n = 2)
30		1.4 + 0.11 (n = 4)	0.65 + 0.06 (n = 2)
50		3.4††	1.1 (n = 1)
100		6.8††	1.2 (n = 1)
Using BE only		% BRH = (Conc. A1254 × 48.8) - 8.4	R ² = 0.864
Using all PCB data		% BRH = (Conc. A1254 × 82.8) - 22	R ² = 0.902

- * Bedded exposure.
 ** From day 0 sample.
 † Suspended exposure.
 †† Concentrations were estimates from the concentration in BRH material and the percentage of BRH in the exposure sediment.

Table 17

Predicted Percentage of BRH Material in Sediments Required To Achieve the
Measured Tissue Residue Values in *N. incisa* from Field Station in CLIS*

Collection Cruise	Station		
	CNTR	400E	1000E

Calculation Based on PCB (A1254)

T + 0	NA**	NA	21.
T + 2	NA	43.	22.
T + 8	NA	48.	40.
T + 16	NA	60.	14.
T + 26	NA	25.	10.
T + 44	22.	20.	7.0
T + 74	26.	17.	3.8
T + 141	35.	10.	10.

Calculation Based on SUM

T + 0	NA	NA	NCA†
T + 2	NA	54.	12.
T + 8	NA	62.	4.2
T + 16	NA	20.	7.0
T + 26	NA	16.	0
T + 44	16.	15.	0
T + 74	58.	4.0	0
T + 141	24.	0	7.0

* Each value was calculated based on the laboratory, bedded-exposure-generated exposure-residue relationship for the compound.

** NA = Organisms not available.

† NCA = No chemical analysis.

130. A second exposure estimate, resulting from laboratory suspended exposure studies, is presented as milligrams per litre BRH for each station and collection date in Table 18. *Nephtys incisa* at CNTR were buried during

Table 18
Estimated Concentrations of BRH Sediment (mg/l) Suspended at
Sediment-Water Interface Based on PCB Concentrations
in Field Collected *N. incisa*

Date	Cruise	Station			
		CNTR	400E	1000E	REFS
17 Apr 82		--	0	--	0
16 Nov 82		--	0	--	2
16 Feb 83		--	9	--	3
12 Apr 83		--	15	--	8
02 Jun 83	T + 2	--	95	43	2
03 Jul 83	T + 6	--	114	44	2
06 Sep 83	T + 16	--	131	88	12
29 Nov 83	T + 26	--	51	26	0
20 Mar 84	T + 44	47	38	10	0
16 Oct 84	T + 74	53	29	10	3
24 Jan 86		76	5	4	0

disposal of the dredged material and did not recolonize the dredged material mound until the spring of 1984. When the worms recolonized the mound, they were sampled. The data in Table 18 display clear spatial and temporal trends. The highest estimates were in the immediate vicinity of the disposed BRH material (400E) during the summer of 1983.

131. Estimated from physical data. The suspended sediment concentrations at 1 m above the bottom were used to predict the concentration of BRH suspended sediment at the sediment-water interface. Details of these calculations are described in Pesch et al. (1987). For the upper bound calculation, the suspended solids were assumed to be entirely BRH material. This approach gave estimates of exposure ranging from 100 to 10 mg/l BRH for quiescent conditions to 300 to 30 mg/l BRH for storm conditions. For a more probable estimate of exposure, the percentages of BRH sediment in the 0- to 2-cm surface

layer at CNTR, 400E, and 1000E from immediately after disposal (June 1983 to October 1985) were calculated from analytical data (Table 19). The

Table 19
Percent BRH Sediment in the Surficial Sediments at the FVP Disposal Site Calculated from Analysis of Sediments

<u>Date</u>	<u>Cruise</u>	<u>Station</u>		
		<u>CNTR</u>	<u>400E</u>	<u>1000E</u>
Jun 83	T + 2	44.5	12.5	1.8
Jul 83	T + 6	15.0	3.3	1.6
Sep 83	T + 16	32.0	4.9	2.0
Dec 83	T + 26	32.8	9.5	4.4
Mar 84	T + 44	4.4	1.9	1.8
Jun 84		9.5	0.5	0.7
Sep 84		10.0	3.5	0.5
Oct 84	T + 74	2.6	0.2	1.6
Dec 84		35.1	0.0	1.0
Oct 85	T + 125	0.2	0.0	0.0

combination of these percentages and the TSS concentrations predicted for the sediment-water interface result in concentrations of BRH suspended sediments at the sediment-water interface for each station and sampling date (Table 20). The calculated predictions are shown for a 1x and 10x enrichment. The enrichment used depends on the hydrographic conditions. Estimates of the concentration of BRH in milligrams per litre at the sediment-water interface are shown for TSS concentrations at 1 m above the bottom under normal conditions (10 mg/l) and under storm conditions (30 mg/l).

132. The sediment samples used for the percent calculations were not replicated and, therefore, no variability estimates are available. However, certain trends in the data are evident (Table 19). There is a gradient of BRH material that is a function of both distance from the center of the mound and time from disposal. BRH sediment concentrations were highest at CNTR immediately after disposal, and decreased significantly through October 1984. Concentrations were elevated in December 1984 at CNTR. The BRH concentrations at 400E also decreased through time and, after March 1984, were only slightly

Table 20
Concentration of BRH (mg/l) at the Sediment-Water Interface for
TSS Concentrations of 30 mg/l and 10 mg/l at 1 m Above
the Bottom and an Enrichment of 10**

<u>Date</u>	<u>Cruise</u>	<u>Station</u>					
		<u>CNTR</u>		<u>400E</u>		<u>1000E</u>	
		<u>300</u>	<u>100</u>	<u>300</u>	<u>100</u>	<u>300</u>	<u>100</u>
Jun 83	T + 2	133.5	44.5	37.5	12.5	5.4	1.8
Jul 83	T + 6	45.0	15.0	9.9	3.3	4.8	1.6
Sep 83	T + 16	96.0	32.0	14.7	4.9	6.0	2.0
Dec 83	T + 26	98.4	32.8	28.5	9.5	13.2	4.4
Mar 84	T + 44	14.2	4.4	4.7	1.9	5.4	1.8
Jun 84		28.5	9.5	1.5	0.5	2.1	0.7
Sep 84		30.0	10.0	10.5	3.5	1.5	0.5
Oct 84	T + 74	7.8	2.6	0.6	0.2	4.8	1.6
Dec 84		105.3	35.1	0.	0.	3.0	1.0
Oct 85		0.6	0.2	0.	0.	0.	0.

* BRH concentrations for the 1^x enrichment can be obtained by dividing the tabular values by 10.

higher than those at 1000E. These stations did not show the increased BRH concentration found at CNTR. With the exception of the BRH concentration for December 1983, the concentrations at 1000E remained relatively similar throughout the study.

133. The 1- to 2-percent BRH sediment calculated for 1000E represents a quantitatively measured elevation above background and is supported by tissue residue data for the infaunal polychaetes *N. incisa*. Additional documentation of contamination comes from examination of the PAH CENT values, which indicate the presence of BRH sediment. This contamination could have resulted from the initial disposal operation, the errant disposal of BRH material in the vicinity of 1000E, or the continuous transport of contaminated material from the disposal site.

Tissue residues - *Mytilus edulis*

134. PCB patterns. The pattern of electron capturing compound residues present in *M. edulis* deployed at REFS for 1 month at T - 4 is shown in

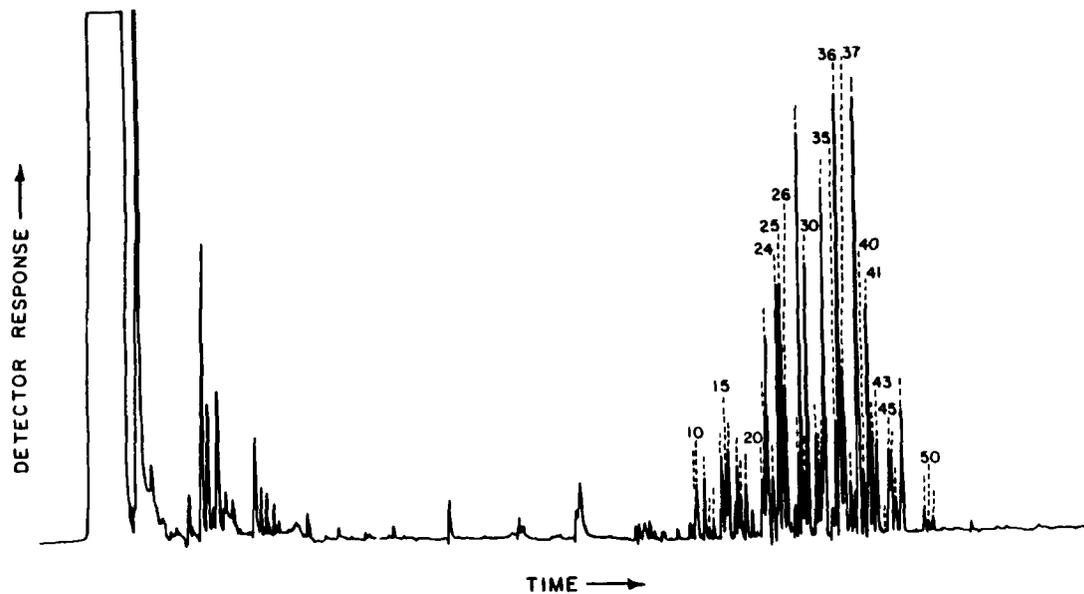
Figure 34 and is representative of that observed in T - 4 organisms from CNTR, 400E, and 1000E. This pattern shows maximum peaks for PCBs in the Cl₆ range. This pattern was found in all *M. edulis* from field deployments with the exception of one sample taken at T + 0 and two samples taken at T + 2.

135. The pattern in *M. edulis* retrieved at T + 0 from 1000E and T + 2 from 400E and 1000E showed the lower molecular weight compounds enhanced relative to the Cl₆ PCB compounds (Figure 34). *Mytilus edulis* with the altered PCB pattern also showed increases in PCB concentrations relative to other field-deployed *M. edulis*. However, differences in two of the peak height comparisons, Peaks 24 and 26, and Peaks 41 and 43, which indicated exposure to BRH material in laboratory studies, were not found in *M. edulis* from field deployments. Peak 37 was relatively large in *M. edulis* at T + 0 from 1000E and T + 2 from 400E and 1000E.

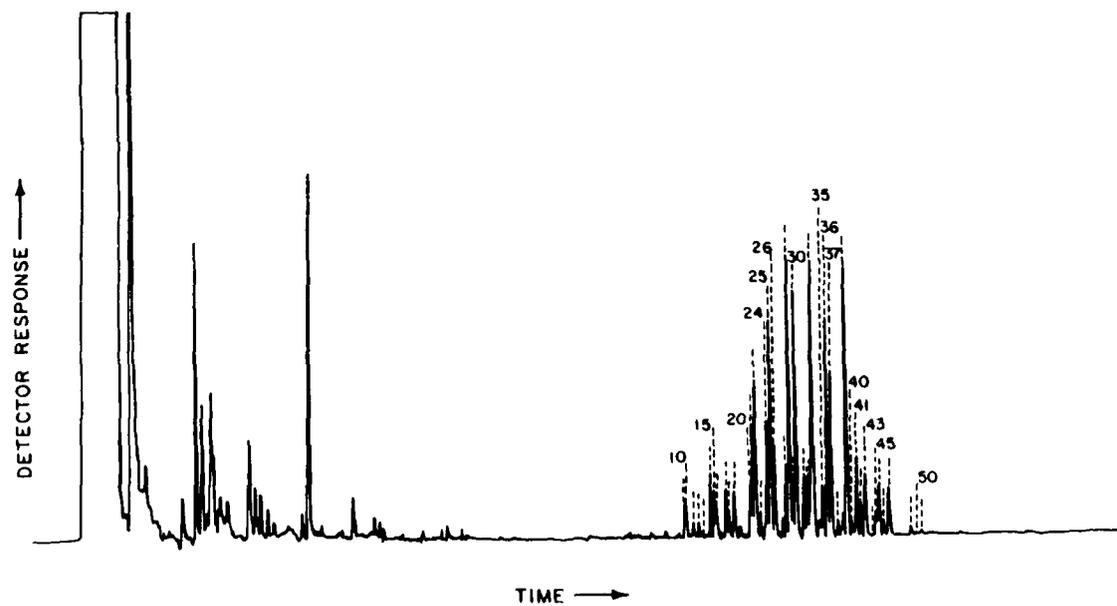
136. PCB concentrations. The concentrations of PCBs in *M. edulis* exposed at the FVP stations before, during, and after disposal of BRH dredged material at CNTR are shown in Figure 35. The most noticeable elevation in PCB residues occurred at T + 0 at 1000E and at T + 2 at 400E and 1000E. A less pronounced elevation above background levels was found at T + 15 at CNTR.

137. PAH patterns. During the FVP study the PAH patterns in *M. edulis* from the reference population in Narragansett Bay were found to vary. Since this population was the source of organisms used for deployment in CLIS, the changes observed are presented. The PAH tissue residues in *M. edulis* collected during the period of the FVP study from the Narragansett Bay reference population showed at least two distinctly different patterns. One of these patterns indicated a dominance of phenanthrene, fluoranthene, and pyrene (Figure 36); the other showed a greater relative abundance of alkyl homologs of molecular weight 178 and 202 PAHs and a greater relative abundance of higher molecular weight PAHs (Figure 36). Mixtures of these patterns also were found in *M. edulis* from Narragansett Bay. No ethylan was found in these samples.

138. The qualitative changes observed in the PAH and ethylan tissue residue patterns in *M. edulis* from all the FVP stations before, during, and after disposal of BRH material in CLIS were similar. The patterns of PAH tissue residues in typical T - 4 samples showed the parent molecular weight 178 and 202 PAHs and the alkyl homologs of those compounds at about the same concentration. In addition, these peaks dominated the tissue residue patterns



a. REF predisposal



b. 400E at T + 2

Figure 34. Capillary column electron capture gas chromatograms of fraction containing PCBs from tissues of *M. edulis* retrieved from REF predisposal and 400E at T + 2

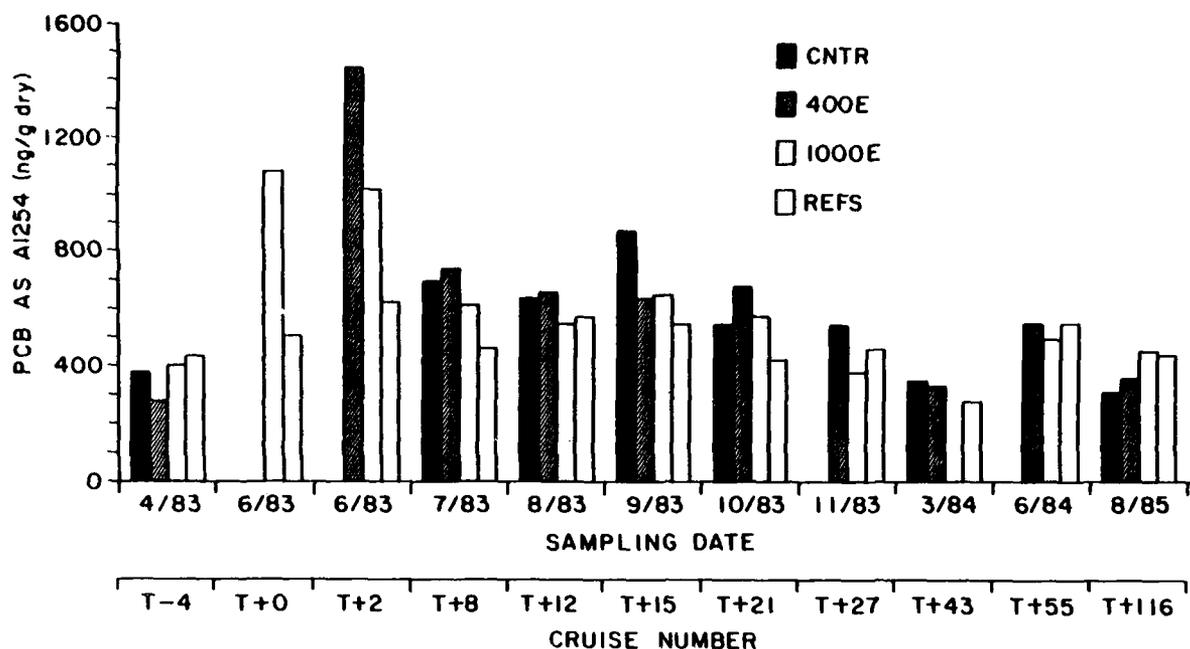


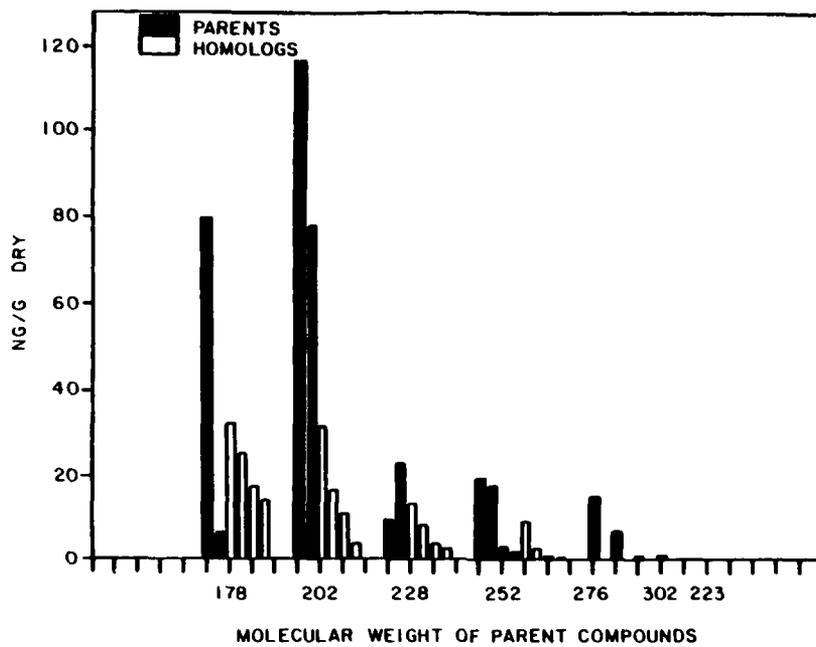
Figure 35. Concentrations of PCBs as Al254 in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

(Figure 37). Only a trace of ethylan was found in these samples. *Mytilus edulis* retrieved at T + 2 show a shift in the pattern of parent compounds toward higher molecular weights. In addition, the alkyl homologs of the molecular weight 178 and 202 PAH compounds are considerably more abundant than the parent compounds, and ethylan is detected (Figure 37).

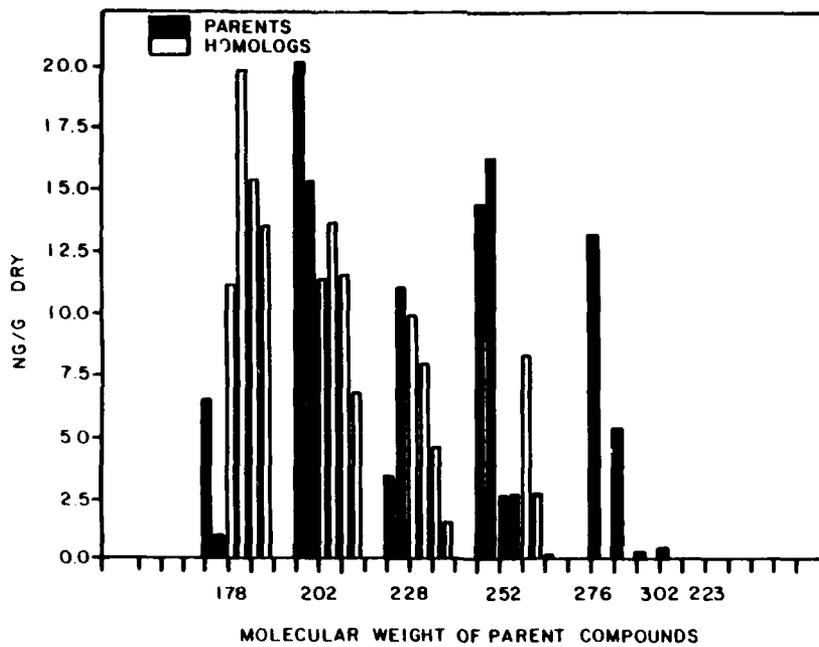
139. *Mytilus edulis* deployed at FVP stations for 1-month intervals and retrieved in the T + 8 to T + 15 time period showed distributions of PAHs with a trend of declining concentrations of the alkyl homologs of 202's relative to the nonalkylated parent compounds (Figure 38). Also, the concentration ethylan declined over this time period.

140. Over extended time periods and using all *M. edulis* exposure times (Table 3), the trend showed that the 252 molecular weight parent compounds tend to become the most abundant PAHs in these patterns, and by T + 116 the 252 compounds predominate (Figure 38). In addition, the CENT of the PAHs appear to show a seasonal trend of increase from winter to spring (Figure 39). The exposure times for some of these *M. edulis* are different, however, and based on the limited data available, the existence of a seasonal trend cannot be confirmed.

141. PAH concentrations. The concentration of phenanthrene and fluoranthene before, during, and after disposal at the field stations are shown in

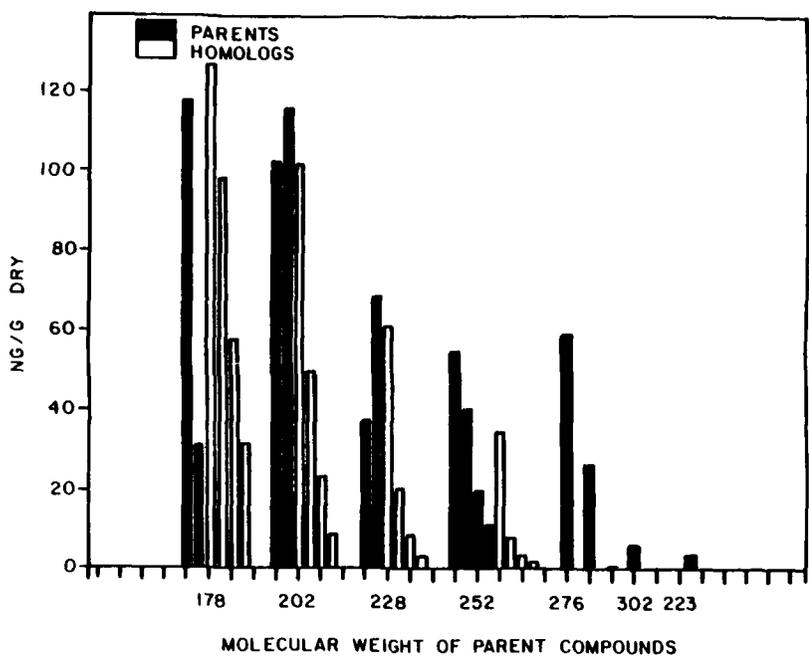


a. June 1983

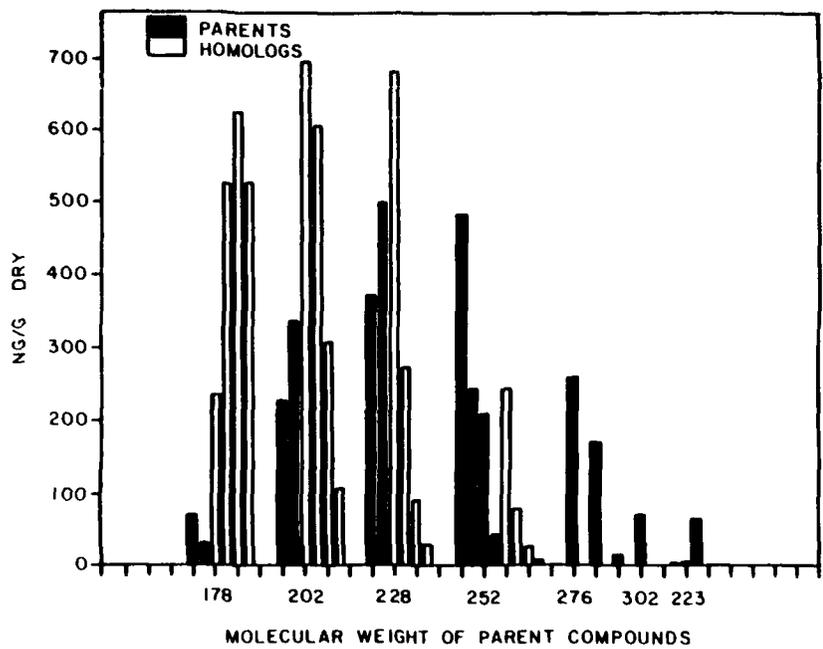


b. September 1983

Figure 36. Bar graphs of PAHs and ethylan in the tissues of *M. edulis* collected from the Narragansett Bay reference population in June 1983 and September 1983

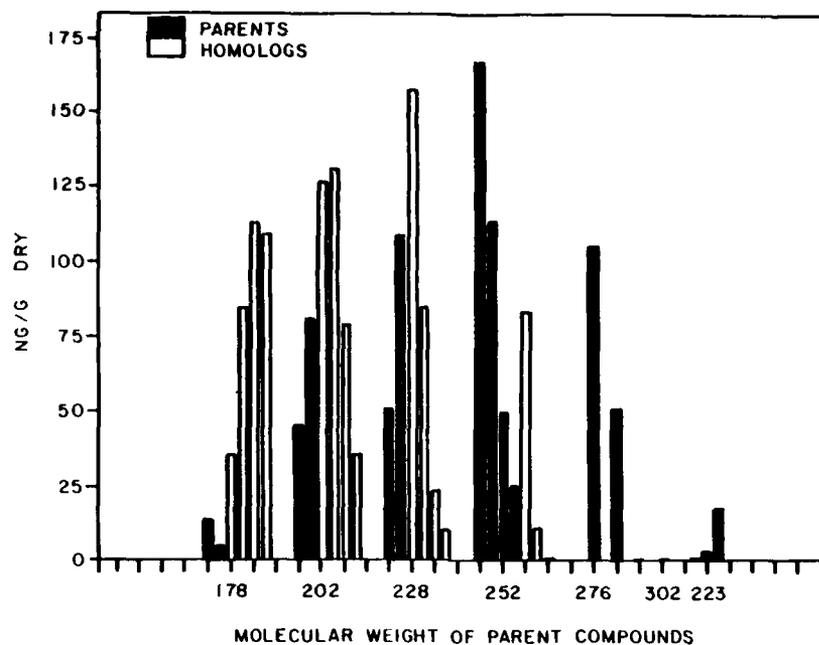


a. T - 4

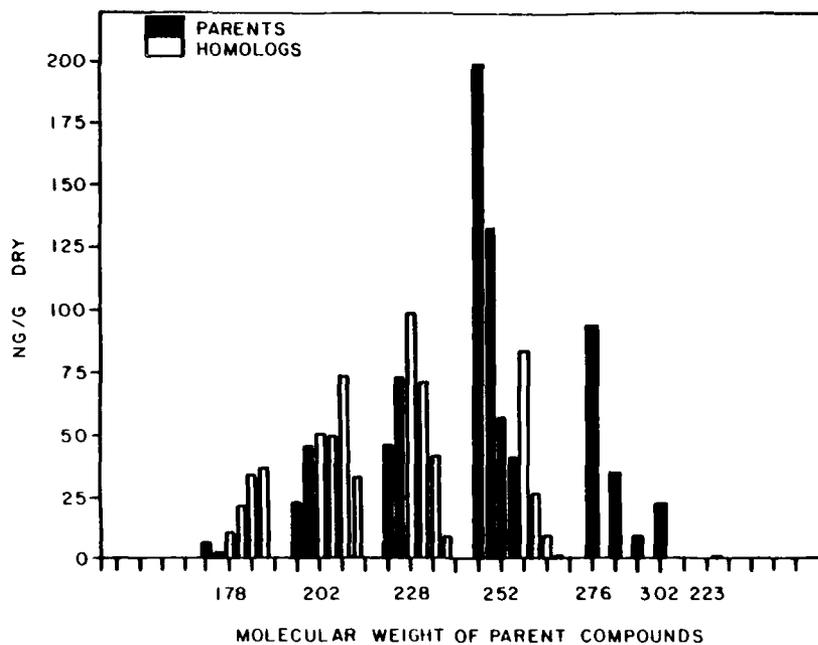


b. T + 2

Figure 37. Bar graphs of PAHs and ethylan in the tissues of *M. edulis* retrieved from 400E at T - 4 (predisposal) and T + 2 (immediately postdisposal)



a. T + 8



b. T + 116

Figure 38. Bar graphs of PAHs and ethylan in the tissues of *M. edulis* retrieved from 400E at T - 8 and T + 116

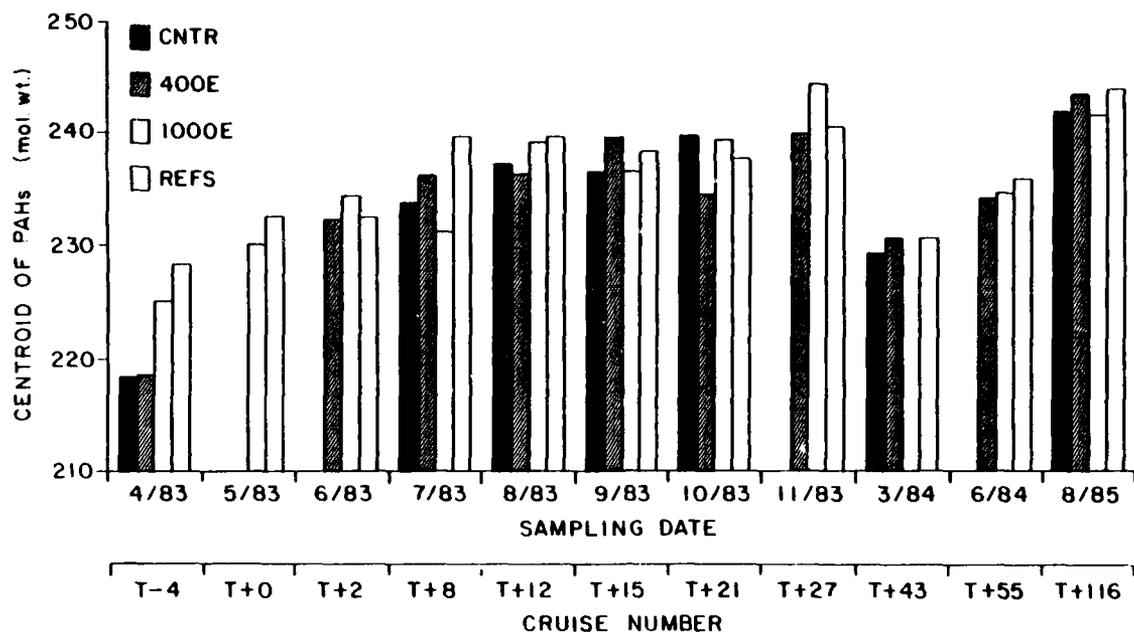


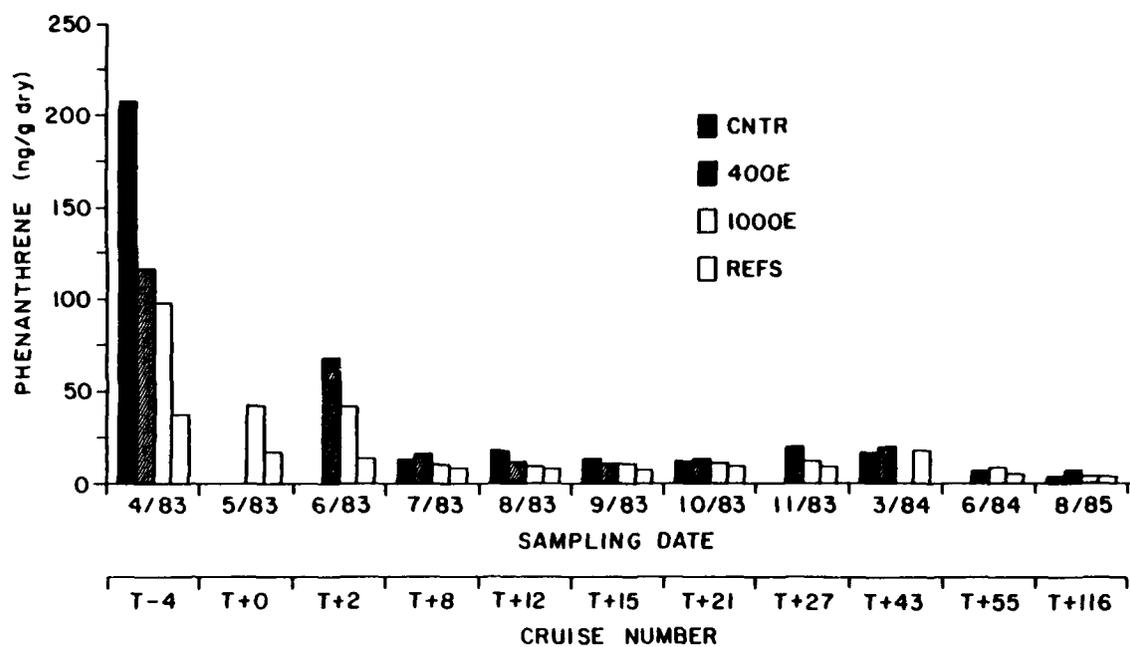
Figure 39. CENT in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

Figure 40. The concentrations of these compounds in *M. edulis* decreased throughout the disposal period from relatively high values in predisposal samples, and appeared to level out after disposal.

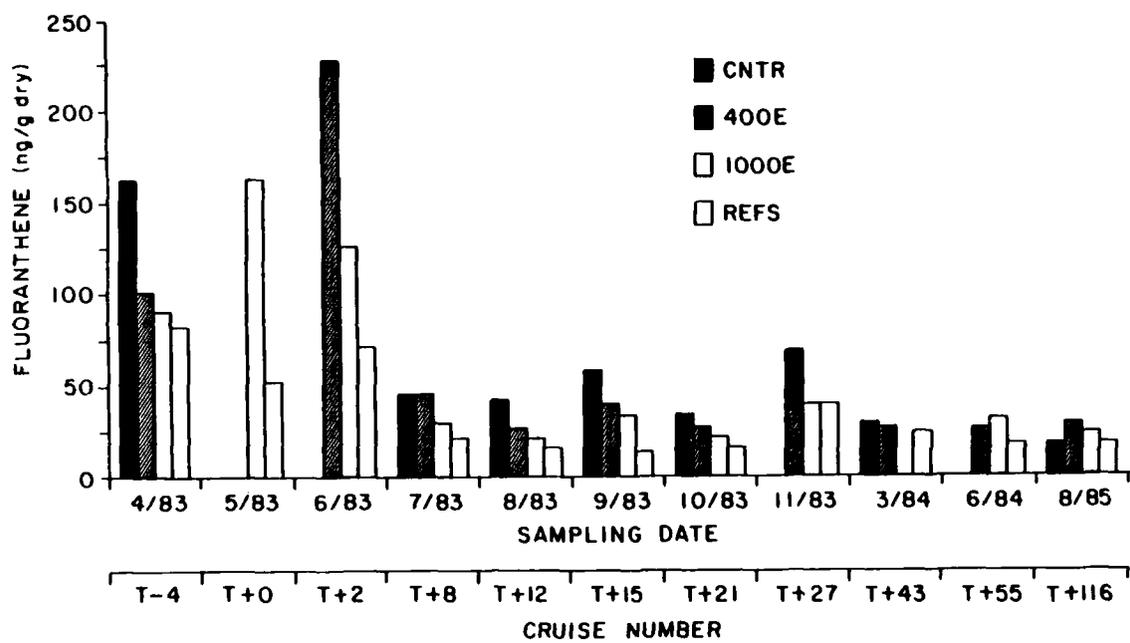
142. Lower values for CENT were found at CNTR and 400E than at 1000E and REFS prior to disposal (Figure 39). After disposal, and for the remainder of the study, however, clear distinctions in the PAH CENT values between stations were not observed.

143. Concentrations of SUM, benzo(a)pyrene, ethylan, and alkyl homologs of the 178 PAHs showed increases that corresponded to the disposal of BRH dredged material at CNTR (Figures 41 and 42). These compounds showed increases at stations 400E at T + 2 (sample at 400E at T + 0 was not recovered) and 1000E at T + 0 and T + 2. In subsequent samples these concentrations decreased to near background levels. The concentration of SUM of PAHs showed a noticeable increase only at 1000E at T + 0 (Figure 42).

144. Metals. The concentrations of copper, chromium, cadmium, and iron in samples of *M. edulis* deployed at the FVP stations are shown in Figures 43 and 44. No consistent pattern of metal accumulation in *M. edulis* as a result of disposal of BRH dredged material at CNTR was observed. Chromium concentrations were elevated in all *M. edulis* samples collected at T + 21 and T + 27

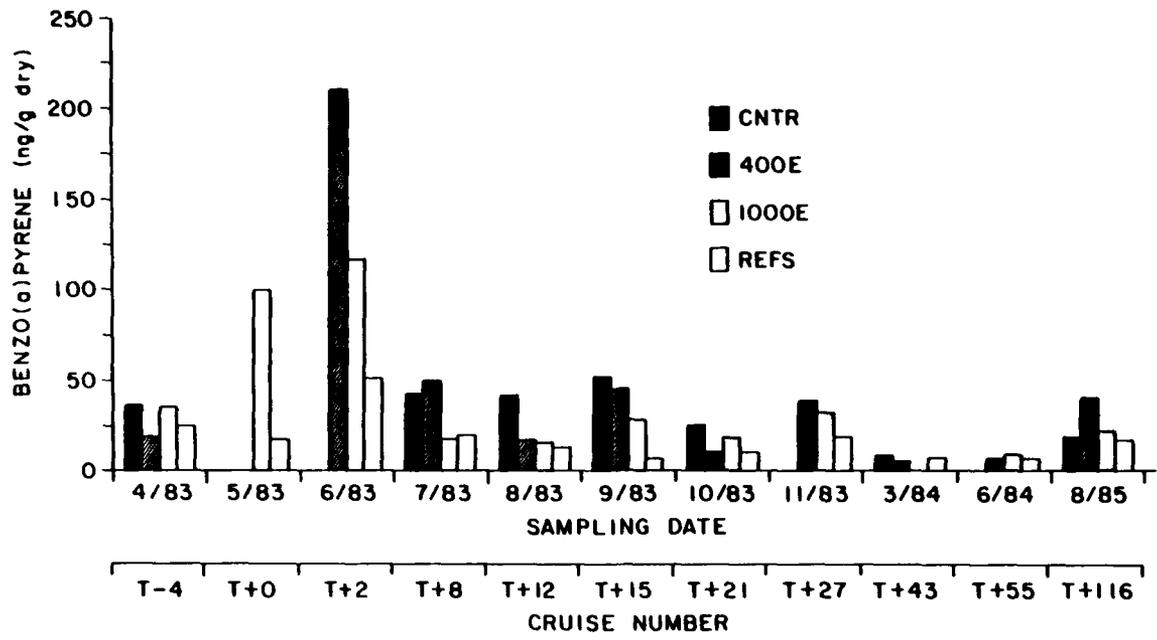


a. Phenanthrene

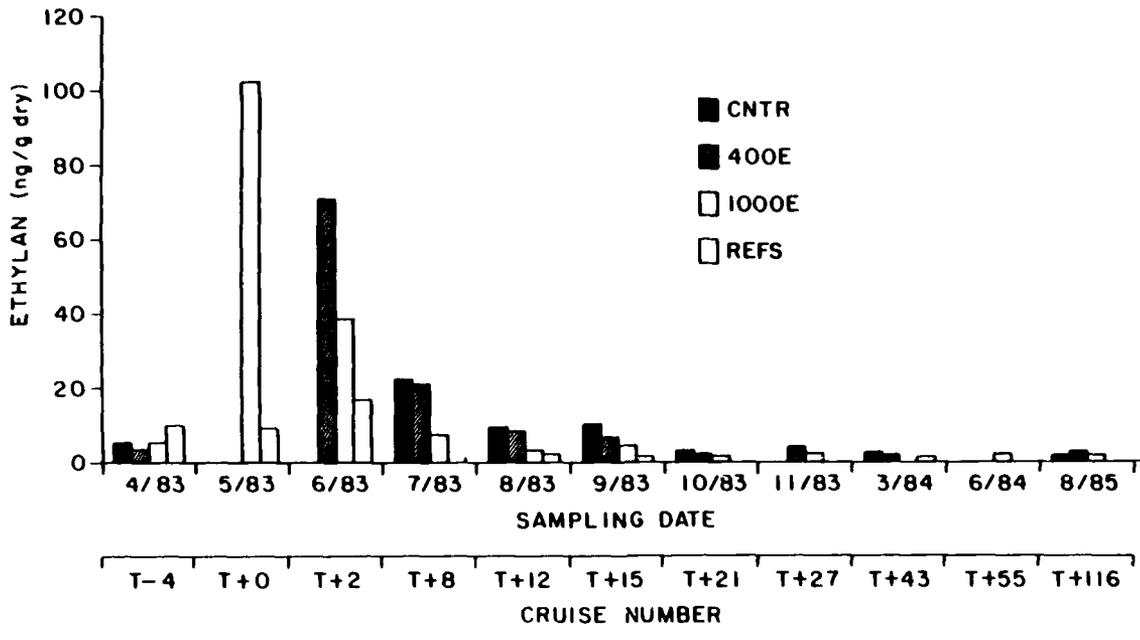


b. Fluoranthene

Figure 40. Concentrations of phenanthrene and fluoranthene in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

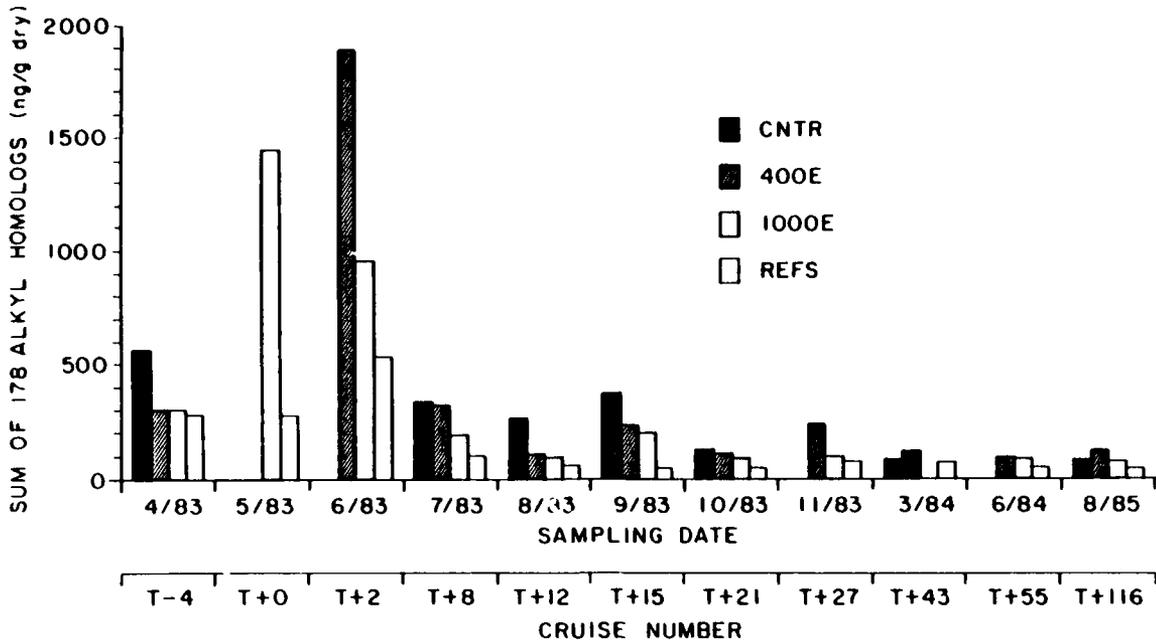


a. Benzo(a)pyrene

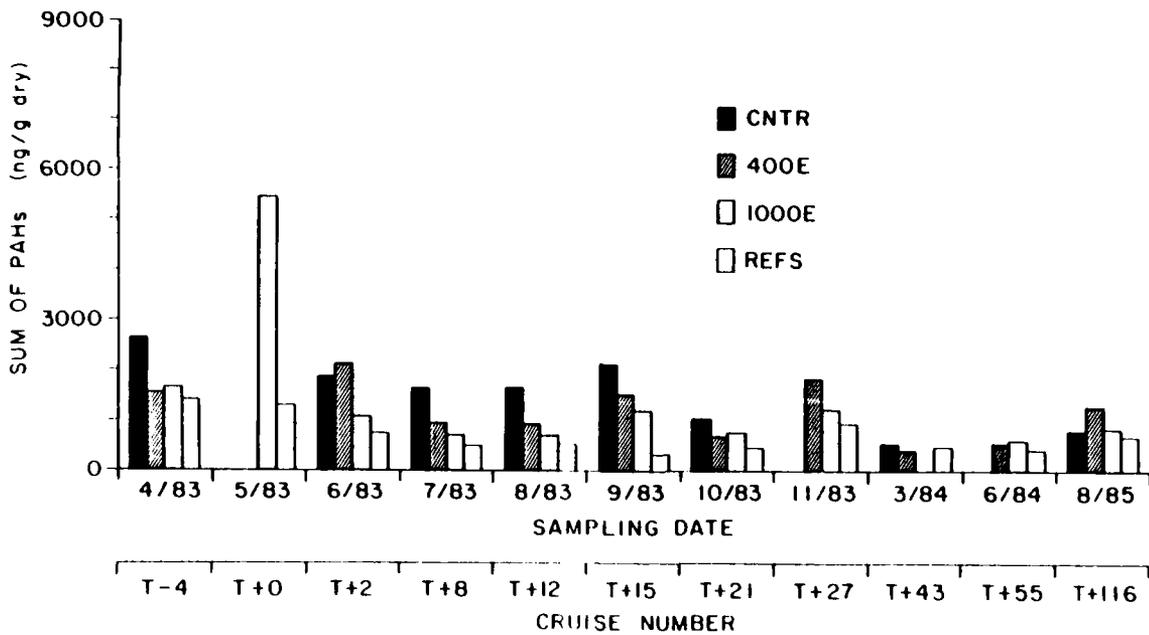


b. Ethylan

Figure 41. Concentrations of benzo(a)pyrene and ethylan in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

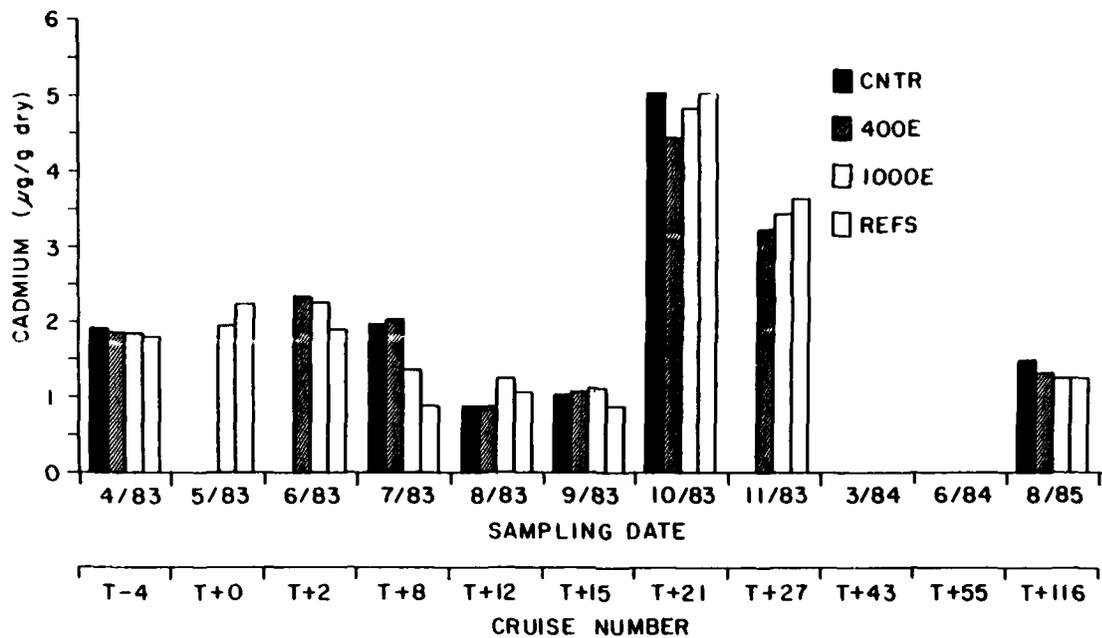


a. Sum of 178 alkyl homologs

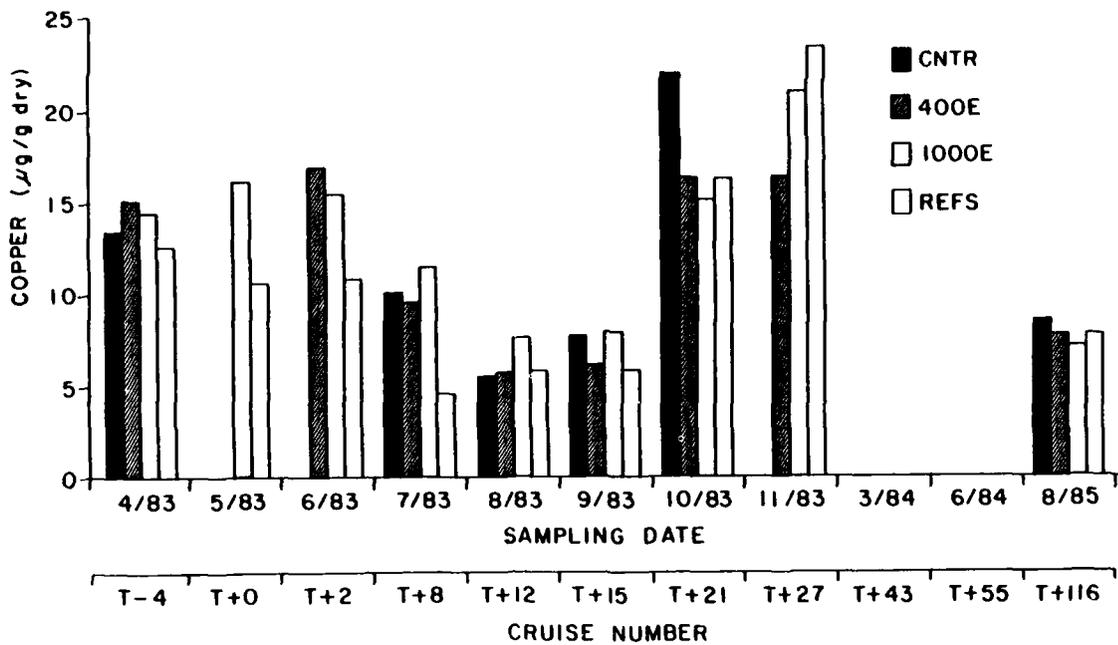


b. SUM of PAHs

Figure 42. Concentrations of the sum of 178 alkyl homologs and SUM of PAHs in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

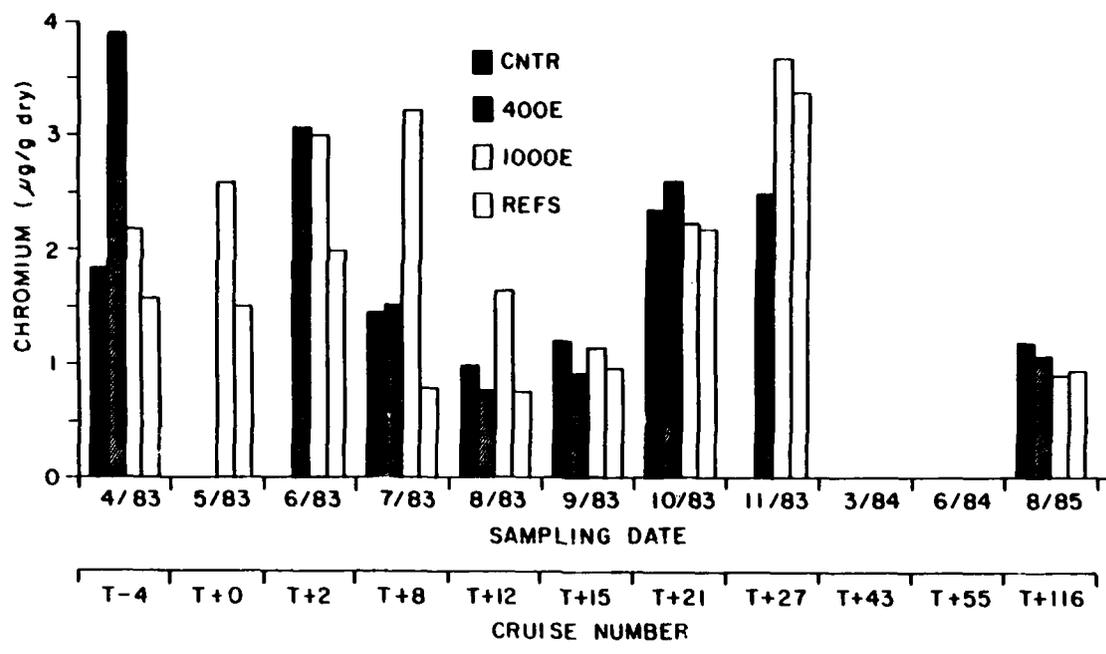


a. Cadmium

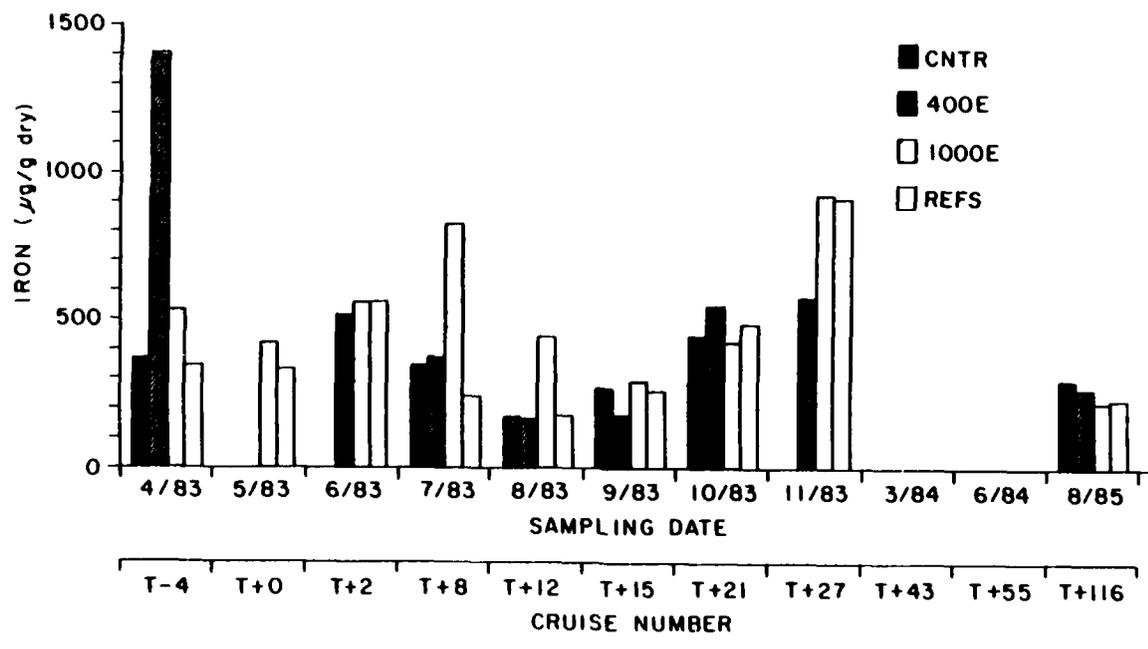


b. Copper

Figure 43. Concentrations of cadmium and copper in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown



a. Chromium



b. Iron

Figure 44. Concentrations of chromium and iron in the tissues of *M. edulis* retrieved from the specified FVP stations on the sampling dates shown

relative to concentrations in the other samples. These two samples were deployed for 7 and 3 months, respectively, and the increased concentrations observed may have been a consequence of increased exposure times.

Tissue residues - *Nephtys incisa*

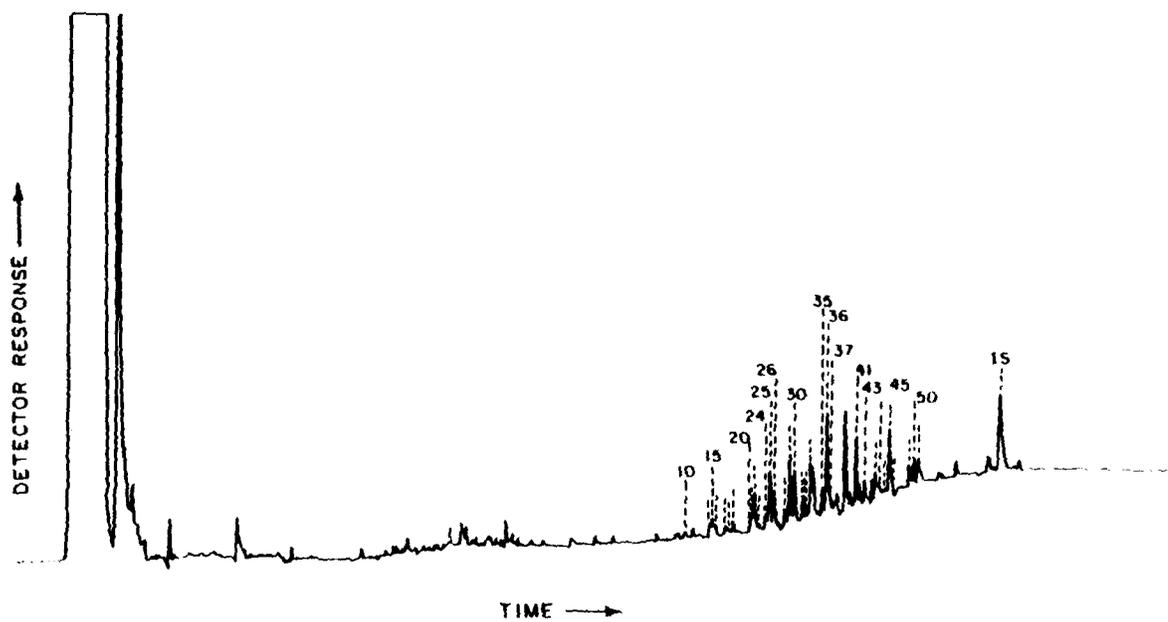
145. PCB patterns. The PCB patterns in predisposal *N. incisa* from all FVP stations and from REFS at all sampling dates were similar. This pattern showed peak heights with Peak 24 < Peak 26, Peak 36 > Peak 37, and Peak 41 > Peak 43 (Figure 45). This pattern was altered in postdisposal *N. incisa* from stations near the disposal mound and resulted in peak heights with Peak 24 > Peak 26, Peak 37 elevated relative to Peak 36, and Peak 43 elevated relative to Peak 41 (Figure 45). This pattern is called *N. incisa* "BRH pattern." Gradations in the degree of alteration of the background pattern to the BRH pattern were observed during the study. *Nephtys incisa* from CNTR showed the BRH pattern. Organisms from 400E and 1000E at T + 2 to T + 16 showed small alterations from the background pattern and later samples at 400E and 1000E showed these changes only very slightly. By T + 140 only slight differences between patterns at 400E, 1000E, and REFS were observed.

146. PCB concentrations. The PCB tissue residue concentrations found in *N. incisa* from the FVP stations are shown in Figure 46. Prior to disposal of BRH material at CNTR, the PCB concentrations in *N. incisa* from REFS and 400E were about equal. After disposal, the PCB tissue residue concentrations in *N. incisa* from 400E, 1000E, and CNTR increased while those in *N. incisa* from REFS remained about the same.

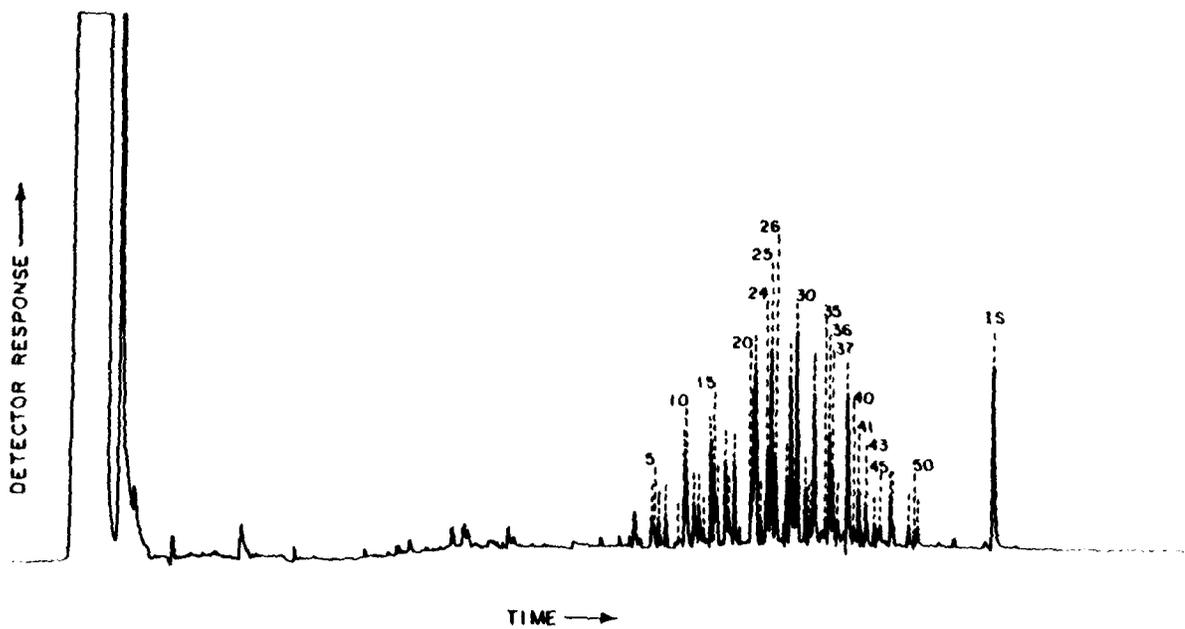
147. At 400E the PCB concentrations in *N. incisa* increased by approximately a factor of three immediately after disposal of BRH material. By T + 28 the tissue concentration of PCBs had decreased by approximately a factor of two from their highest level, and then slowly decreased to background levels by the last sampling at T + 140.

148. *Nephtys incisa* from 1000E indicated an increase in PCB tissue residues in the first 16 weeks after disposal, followed by a decrease to near those levels in *N. incisa* from REFS at T + 44 and T + 74.

149. Sufficient *N. incisa* for chemical analysis were first obtained at CNTR at T + 44. Evidently, these organisms had migrated to the site from adjacent areas because they were too large to have resulted from growth of juveniles on the mound postdisposal. Subsequent samples of *N. incisa* at CNTR



a. REFS at T + 140



b. CNTR at T + 140

Figure 45. Capillary column electron capture gas chromatograms of the fraction containing PCBs from the tissues of *N. incisa* collected from REFS at T + 140 and CNTR at T + 140

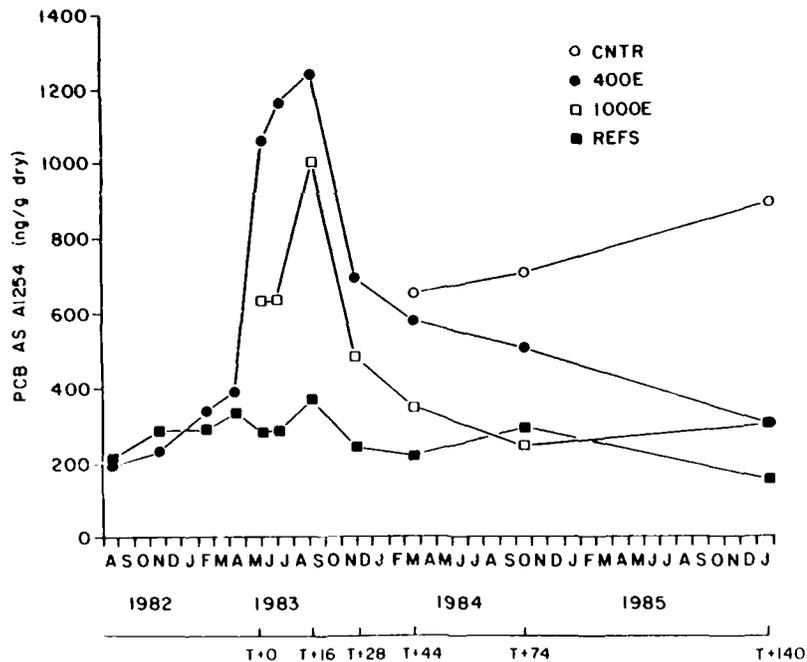


Figure 46. Concentrations of PCBs as Al254 in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

at T + 74 and T + 144 showed what appeared to be an increasing trend in PCB concentrations.

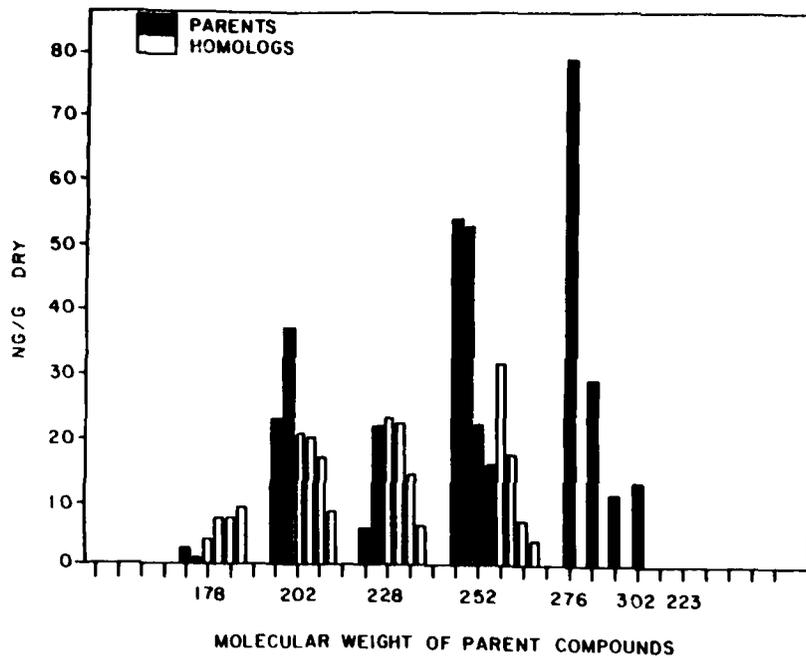
150. The concentrations of PCBs in *N. incisa* from REFS were relatively uniform over the study period.

151. PAH and ethylan patterns. All *N. incisa* from REFS and predisposal *N. incisa* from CNTR, 400E, and 1000E showed a pattern that was similar to the background pattern (Figure 47). Ethylan was not found in these samples.

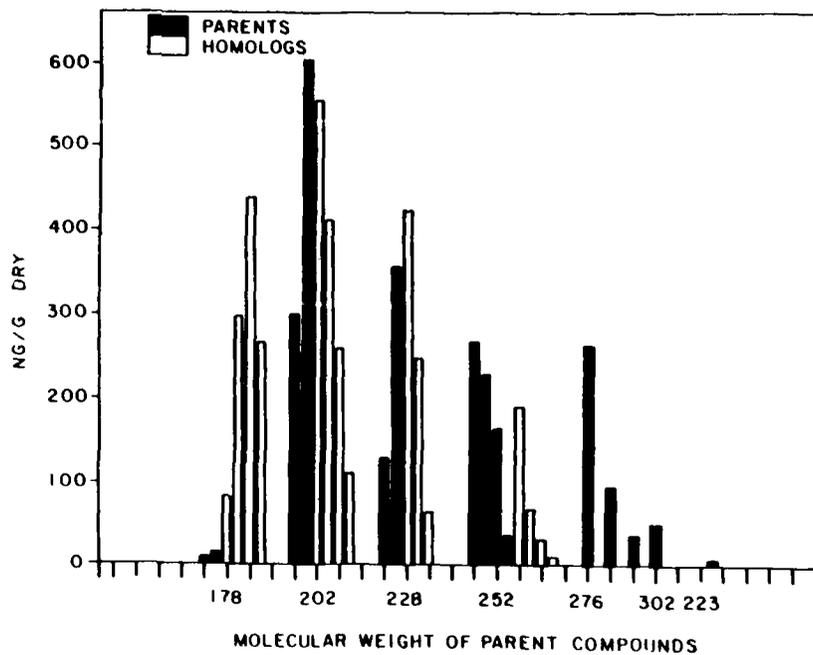
152. *Nephtys incisa* were not found at CNTR in sufficient biomass for an analytical sample unit T + 44. The pattern of PAHs and ethylan in these samples showed the BRH exposed pattern (Figure 47). At T + 140 the BRH pattern was still evident in *N. incisa* from CNTR.

153. At 400E the patterns of PAHs and ethylan in *N. incisa* changed from the background pattern predisposal to the BRH pattern postdisposal, but only a slight amount of ethylan was found in these samples. During the postdisposal period, the pattern in *N. incisa* changed from the BRH pattern to the background pattern.

154. PAH residues in *N. incisa* from 1000E at T + 2 through T + 44 showed the BRH pattern, but by T + 140 the pattern had changed to the



a. REFS



b. CNTR at T + 44

Figure 47. Bar graphs of PAHs and ethylan in the tissues of *N. incisa* collected at REFS and CNTR at T + 44

background pattern. No ethylan was found in 1000E *N. incisa*.

155. PAH and ethylan concentrations. Exposure to BRH sediments caused measurable accumulation of PAHs in *N. incisa* at the field stations, but ethylan did not appear at detectable concentrations except at CNTR. The concentrations of PAHs in *N. incisa* from all stations are shown in Figures 48-51. There was a correspondence between the tissue residue concentration of these compounds in *N. incisa* and the temporal and spatial proximity of the sample to the BRH disposal mound.

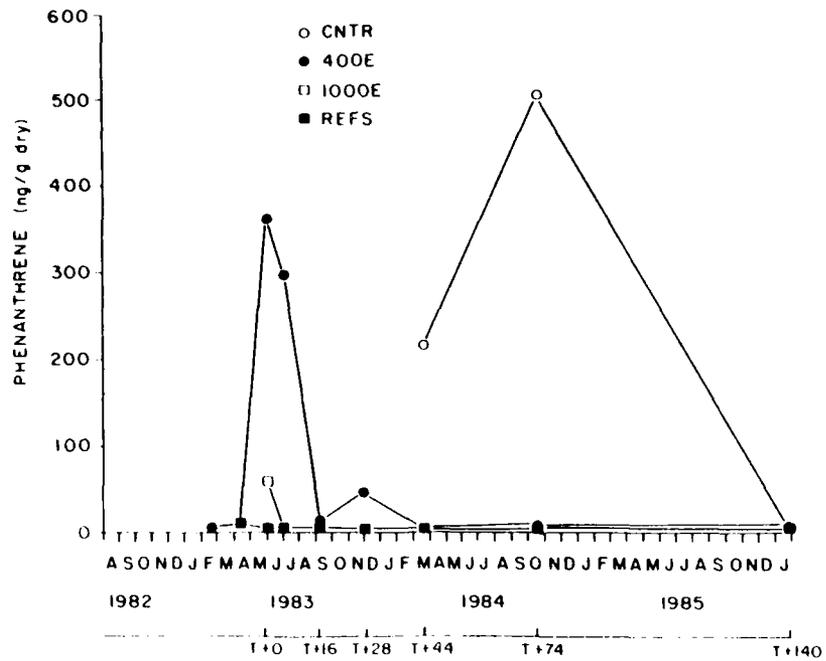
156. *Nephtys incisa* from REFS shows a relatively constant level of PAHs over the study period. The concentration of PAHs in *N. incisa* at T + 2 and T + 8 from 400E were elevated relative to those predisposal, but by T + 16 they had decreased considerably. PAH residues continued to slowly decrease to background values by T + 74. *Nephtys incisa* from 1000E showed elevated tissue concentrations at T + 2, but the concentrations in subsequent samples (through T + 44) decreased to near background levels. *Nephtys incisa* from CNTR sampled at T = 44 showed an elevation in the concentration of PAHs above background values and *N. incisa* samples from this station were still elevated at T + 140.

157. Metals. The tissue residue concentrations of metals from field-collected *N. incisa* showed no clear temporal or spatial trends (Figures 52 and 53). The concentration of cadmium, chromium, and copper in three samples of *N. incisa* from CNTR (T + 44, T + 74, T + 140) decreased and then increased (Figure 53). These concentration changes are opposite to those observed for phenanthrene, sum of 178 alkyl homologs, fluoranthene, SUM, and ethylan (Figures 48-51). These differences may be due to dissimilar bioavailability or uptake/depuration/metabolism of metals when compared with PAHs and ethylan in sediments at CNTR.

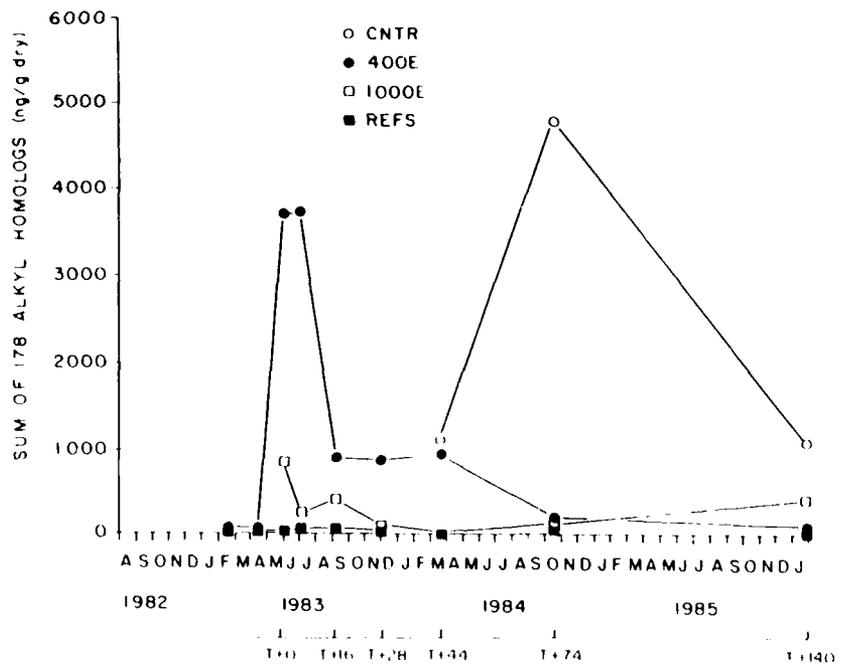
Cluster Analysis of Tissue Residues

Mytilus edulis

158. Results of the cluster analysis with the organic residue data in *M. edulis* suggested several general observations. First, the samples that were most similar included all the field residues collected after T + 2 and the laboratory 0-percent BRH exposures. Second, *M. edulis* collected predisposal (CNTR, 400E, 1000E) and those collected shortly after disposal (1000E at T + 0 and T + 2) were more similar to the other field samples than to the

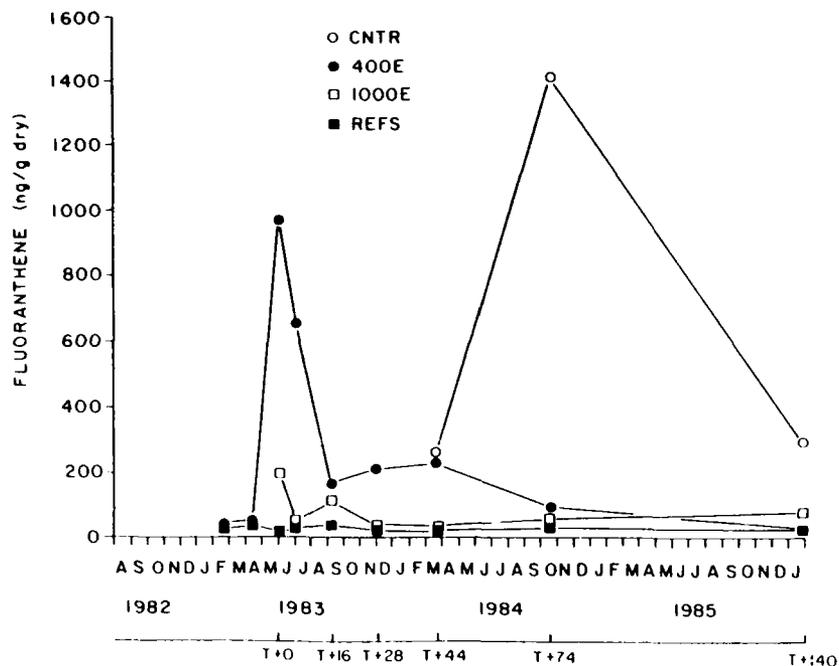


a. Phenanthrene

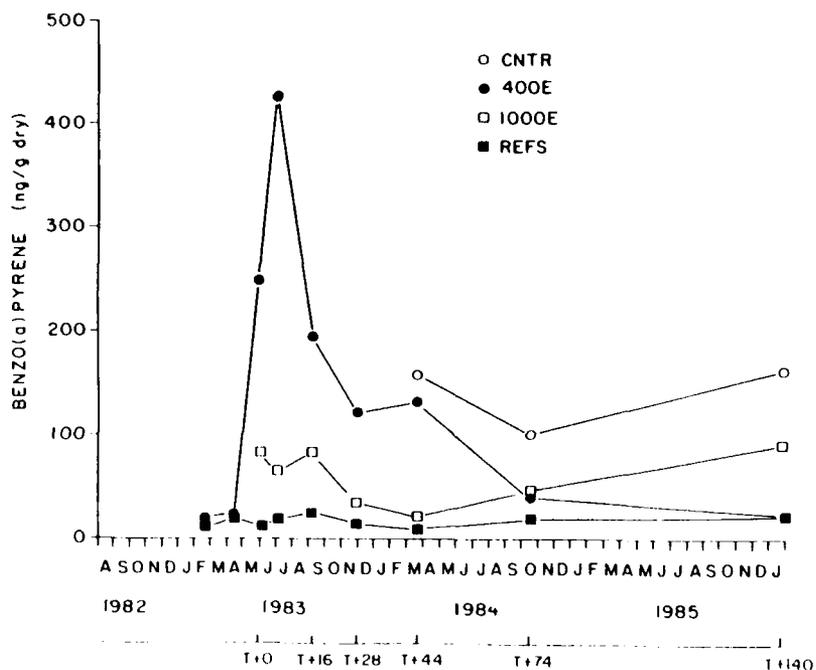


b. Sum of 178 alkyl homologs

Figure 48. Concentrations of phenanthrene and the sum of 178 alkyl homologs in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

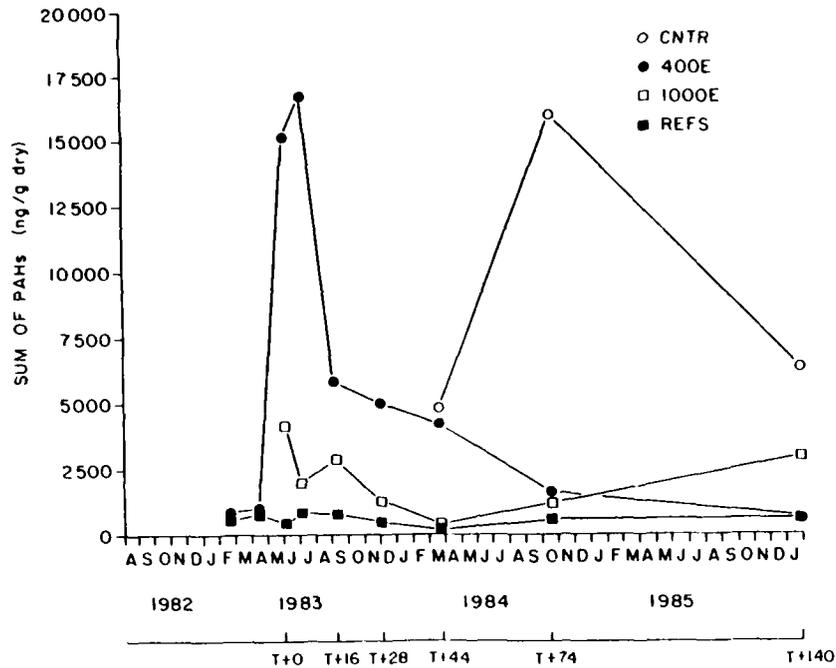


a. Fluoranthene

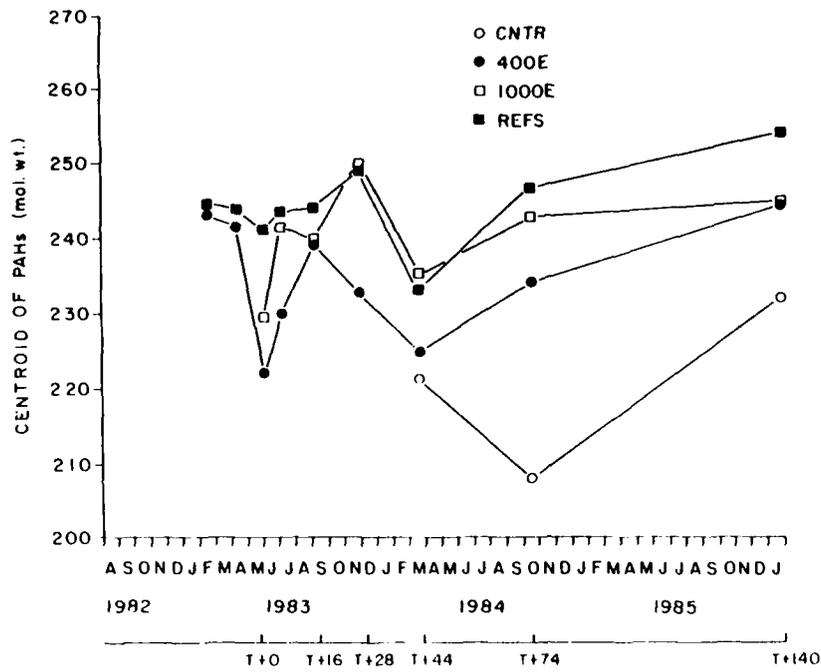


b. Benzo(a)pyrene

Figure 49. Concentrations of fluoranthene and benzo(a)pyrene in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

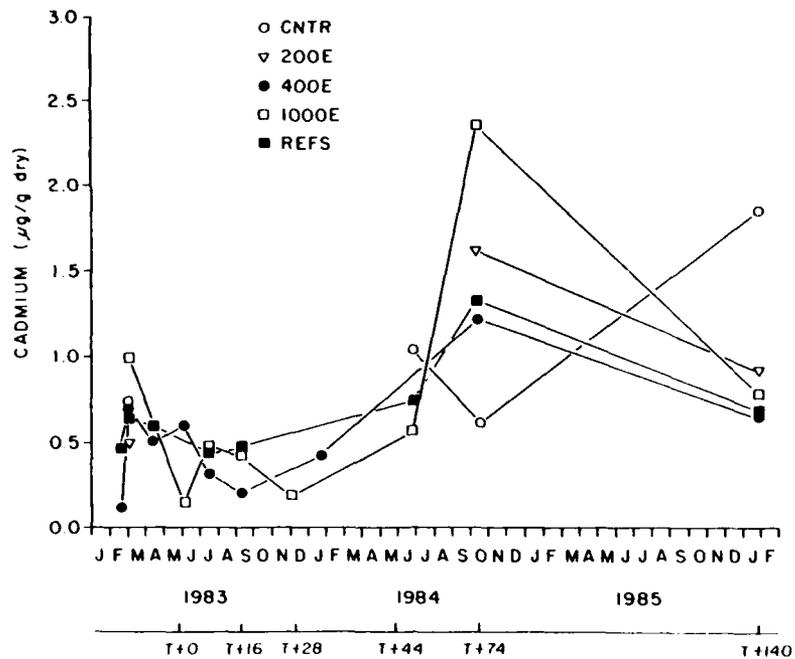


a. SUM of PAHs

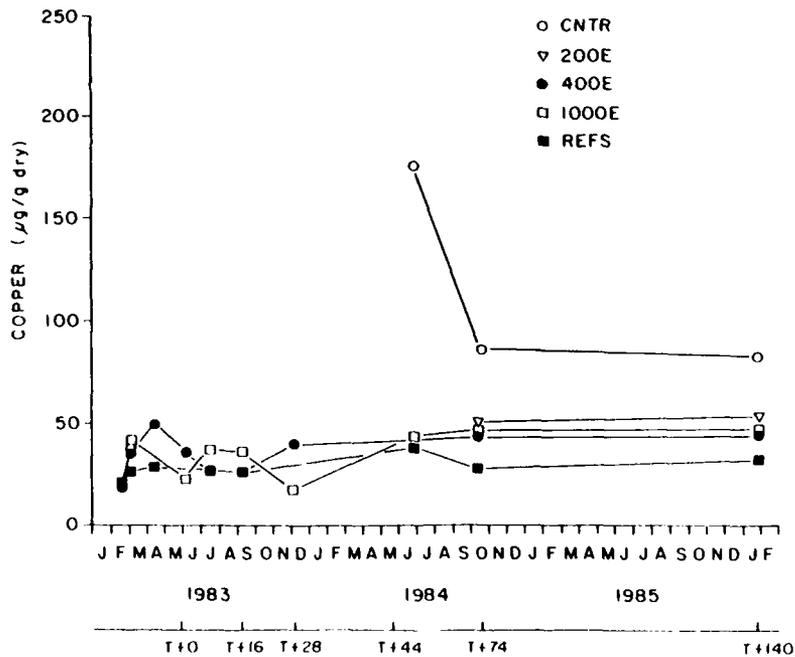


b. CENT of PAHs

Figure 50. Concentrations of SUM of PAHs and CENT of PAHs in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

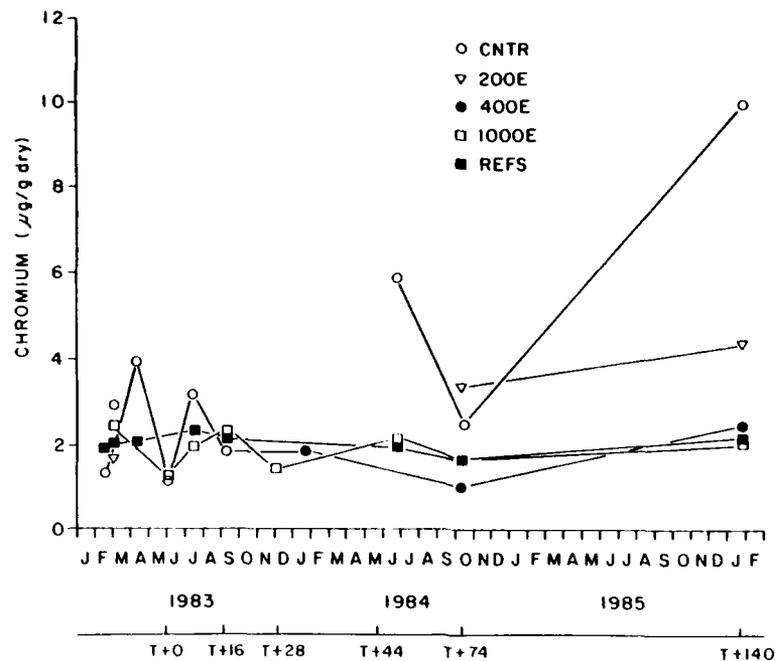


a. Cadmium

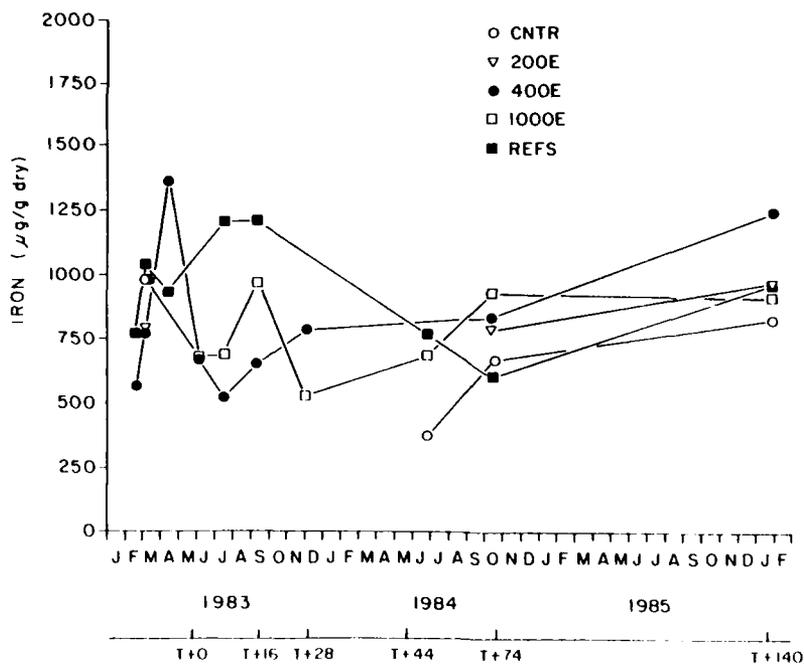


b. Copper

Figure 52. Concentrations of cadmium and copper in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates



a. Chromium



b. Iron

Figure 53. Concentrations of chromium and iron in the tissues of *N. incisa* collected at the specified FVP stations and sampling dates

PART IV: DISCUSSION

160. This study used an observational approach to compare trends observed in the bioaccumulation of contaminants in laboratory studies with those found in organisms exposed in the field. Specifically, the types, molecular weight ranges (distributions), and relative abundances (patterns) of contaminants accumulated by *M. edulis* and *N. incisa* exposed to suspended or bedded BRH sediment in laboratory studies were compared with those accumulated by deployed (*M. edulis*) or indigenous (*N. incisa*) organisms at the FVP field site. Field exposure concentrations were calculated from the relationship between bioaccumulation of contaminants in laboratory exposures to known concentrations of BRH sediments, and the residue concentrations in field exposed organisms. These calculated field exposures were compared with estimates of field exposures predicted from available empirical data.

161. In order to quantify the relationship between the concentration of a contaminant bioaccumulated in a laboratory organisms with that bioaccumulated in an organism exposed in the environment, the relationship between exposure and accumulation must be established.

162. In the present study the approach has been to determine the exposure-residue relationship in the laboratory and then use this relationship to calculate exposures from residue values from field-exposed organisms. This approach makes the assumption that similar exposure-residue relationships exist in the laboratory and in the field. This approach was adopted early in the study when it became apparent that insufficient measurements of contaminant concentrations would be available to accurately establish field exposure. In order to establish an exposure-residue relationship in the laboratory that will have applicability in the field, steady-state contaminant concentrations in organisms must be reached, and the concentration of contaminants in organisms and in the exposure zone must be measured. A steady-state contaminant concentration can be established in an organism by continuing to expose organisms until only small differences are observed in contaminant tissue residue concentrations between successive organism sampling times; or it can be estimated from uptake and depuration rate constants if sufficient data of this type are available. To establish the exposure zone for an organism, the uptake pathway(s) for accumulation is determined, and concentrations in the appropriate exposure media are measured.

163. The development of a quantitative relationship between exposure and tissue residue for *M. edulis* involved determining the steady-state PCB concentrations in laboratory studies. For the *M. edulis* studies the exposure zone was the water plus suspended particulates. For polychaete worms, however, the establishment of steady-state and the determination of exposure zones were more difficult.

164. Previous work with BRH sediments and the deposit-feeding polychaete *Nereis virens* showed accumulation of PCBs during a 28-day uptake, but it was not known if steady-state PCB concentrations were reached during the test (Lake, Hoffman, and Schimmel 1985). Other work found that steady-state for *N. virens* exposed to PCBs in environmentally contaminated sediments was reached by days 30 and 40 depending upon the sediment (Rubinstein, Lores, and Gregory 1983). Steady-state PCB concentrations were reached between days 35 and 100 (interpolation of graphical data) for *Nereis diversicolor* exposed to sediments spiked with different levels of PCBs (Fowler et al. 1978). Steady-state PCB concentrations were not attained in *N. virens* exposed to spiked sandy sediments (McLeese, Metcalfe, and Pezzack 1980). In general, these studies showed that the time to reach steady-state varied with the polychaete worm and the sediment.

165. In the present study *N. incisa* exposures were continued for 55 days to bedded sediment and 42 days to suspended sediment. The PCB concentrations in the bedded sediment exposures at day 55 for both the 30- and the 10-percent BRH exposures appear anomalously high relative to those in the days 10, 21, and 28 samples. The reason for these high values is unknown.

166. The feeding mode of *N. incisa* is not well understood. These organisms have been called deposit feeders but may actually filter feed and/or feed from surficial sediments.* Consequently, separate laboratory tests were conducted utilizing bedded sediment exposures and suspended sediment exposures. The PCB tissue residue concentrations were similar in *N. incisa* from both tests. Therefore, a determination of the dominant feeding mode and a definition of the exposure zone for these organisms could not be determined from these studies. As a result, assumptions are made regarding the exposure zone for *N. incisa* for comparison purposes and to allow calculations of the field exposure concentrations (see paragraphs 179-180). In the discussion

* Personal communication, 1986, G. Pesch.

that follows, comparisons are made between the exposure and the residue values in laboratory and field. These comparisons are based on several assumptions and in some instances the data necessary to accept or reject the assumptions are not available. These comparisons are not quantitative, but are made to evaluate the degree of success in relating results of laboratory bioaccumulations with those from field studies.

Laboratory-to-Field Linkages

167. To evaluate the success of the laboratory studies for predicting the accumulation of contaminants in field-exposed organisms, the relationships between the tissue residues from laboratory and field studies have been compared. These comparisons include both the patterns and the concentrations of accumulated contaminants (Table 21).

Table 21
Summary Evaluation of Relationships Between
Laboratory and Field Tissue Residues
Resulting from Bioaccumulation

	<i>M. edulis</i>	<i>N. incisa</i>
PCB patterns	+	+
PCB residue concentrations	+	+
PAH and ethylan patterns (PAH only for <i>N. incisa</i>)	0	
PAH and ethylan residue concentrations (PAH only for <i>N. incisa</i>)	+	+
Metal residue concentrations	0	0

Note: The subjective rankings were made after review of all data (chromatograms, bar graphs and summaries of data) from all laboratory and field studies.
 For the + (strongest relationship), ranking patterns and concentrations of contaminants matched in 90% (or more) of the laboratory-to-field comparisons.
 For the 0 (no relationship), no obvious patterns or trends were apparent in the laboratory-to-field comparisons.

168. For organic contaminants in the dredged material, the relationships have been quite good. The distributions and patterns of PCBs accumulated by the *M. edulis* and *N. incisa* exposed to BRH material in laboratory tests and from field exposures matched quite closely; therefore, there was good concurrence between laboratory and field. The PCB residues in laboratory and field organisms increased as a consequence of exposure to BRH material. The development of a predictive quantitative relationship for bioaccumulation for both the laboratory and the field was not straightforward. This was primarily due to the lack of adequate field exposure data to determine exposure concentrations for *M. edulis*, and difficulties in determining steady-state residue values and exposure zones for *N. incisa* in both field and laboratory studies.

169. The PAHs in *M. edulis* from background populations (Narragansett Bay) and predisposal deployments (field stations in CLIS) showed different patterns, and no clear pattern changes as a result of field exposure after disposal could be observed. Therefore, concurrence between PAH patterns in laboratory and field-exposed *M. edulis* could not be found simply due to natural variability. For *N. incisa*, similar PAH pattern changes were observed for both the laboratory and the field exposures to BRH sediment and the pattern concurrence was considered good. Increases in the tissue residue concentrations of several PAHs as a consequence of exposure to BRH material occurred in both the laboratory and the field for *M. edulis* and *N. incisa*. As observed with PCBs, however, the development of predictive quantitative exposure-residue relationships in both laboratory and field was not possible due to the lack of adequate field exposure data and difficulties in determination of steady-state residue values and exposure zones. The concentration of ethylan was found to increase in both organisms in the laboratory studies. Ethylan residues were elevated in field-deployed *M. edulis*, but could not be quantified in *N. incisa* from the field (except at CNTR) due to analytical interferences.

170. Of the metals examined, only copper in *M. edulis* and copper and possibly cadmium in *N. incisa* showed accumulations in laboratory studies. In the field no clear exposure-residue relationships in metal accumulation as an immediate result of the disposal of BRH material were observed in either organism.

171. Cluster analyses can be used to determine the degree of similarity of the organic residue data from *M. edulis* and *N. incisa* from the laboratory

and the field. The degree of concurrence can be used to evaluate the adequacy of the laboratory predictive bioaccumulation tests. In general, all *M. edulis* samples receiving BRH exposure in the laboratory cluster in a different group than the field samples. This indicates that the exposure concentrations used in the laboratory may not have adequately matched field exposures. The quantitative data from this study show that the laboratory exposures to BRH sediment were above those experienced by *M. edulis* in the field. The exception was for *M. edulis* from 400E at T + 2, which received the highest BRH exposure of the field samples and had residues that were more similar to those of the laboratory-exposed *M. edulis* than to residues in the other field samples.

172. For *N. incisa* several cluster groups were found. In general, these cluster groups contained both laboratory and field samples that suggest a correspondence between the laboratory and the field exposure concentrations. However, within the groups receiving laboratory or field exposure to BRH material, the similarities of residues were not strong. This may have resulted from differences in the laboratory and field exposure durations or the lack of attainment of steady-state for organic contaminants in organisms from these exposures.

Field Exposure Estimates

Mytilus edulis

173. Two methods were used to estimate BRH exposure concentrations for field-developed *M. edulis*. The first estimates were made using the laboratory-generated exposure residue relationship for PCBs from Experiment 2 at day 28 and the residue concentrations in field-deployed *M. edulis* (Table 14). Other estimates of BRH exposure concentrations were made using water chemistry data on PCBs and copper (Table 15).

174. Comparison of the tissue residue and water chemistry estimates of BRH concentration in CLIS indicated good correspondence between the two. Several examples demonstrate this point. Tissue residue data (PCBs) from the T + 2 collection (Table 14) indicated that the BRH concentration was estimated to range between 1.4 and 0.8 mg/l at the CNTR station. Water samples from the same station estimated the BRH concentration to range between 1.1 and 0.7 mg/l (Table 15) using the PCB values, and 1.3 and 0.7 using copper values.

Approximately 6 weeks later, BRH concentration estimates, based on PCB tissue residues, were between 0.7 and 0.2 mg/l at the CNTR station (T + 8, Table 14). The corresponding water chemistry estimates of BRH concentrations at the CNTR ranged from 0.2 to 0.1 mg/l using PCBs, and 0.6 to 0.3 mg/l using copper.

175. Both BRH estimates demonstrate that BRH exposure 1 m above the bottom was maximal immediately postdisposal and decreased over time. Spatially, both the PCB tissue residue and water chemistry data indicated that BRH exposure decreased moving away from the CNTR station immediately postdisposal (Tables 14 and 15). This pattern persisted until T + 12, when tissue residues were similar at each station. The loss of the spatial differences in BRH exposures would suggest that exposure from the disposal mound was minimal after this collection period. Temporally, the maximum estimated concentration of BRH material 1 m above the bottom ranged between 1.4 and 0.8 mg/l (tissue residues at T + 2, Table 14). At the time of the next collection this value decreased by approximately one half, and continued to decrease over time.

176. The high estimates of BRH exposure never reached zero, even in the later collections (i.e., T + 55, T + 116). This may indicate that background PCB levels in CLIS contributed to the BRH estimates, including those immediately postdisposal. The low estimate, calculated by subtracting the concentration at the REFS station, was assumed to remove the background concentration present in CLIS. Therefore, the low estimate provided a measure of relative difference between the stations and may have provided the best estimate of actual BRH exposure concentrations. However, even using the high estimates, the data suggest that the integrated exposure of BRH material to *M. edulis*, 1 m above the bottom, was low at all the FVP stations and decreased rapidly following completion of the disposal operation.

Nephtys incisa

177. Since laboratory experiments show that PCBs and other contaminants can be accumulated by *N. incisa* from either bedded or suspended exposure, two separate field exposure concentration estimates were made using the exposure-residue relationship from the laboratory studies. The first estimates were made using the laboratory-generated exposure-residue data for *N. incisa* from the bedded studies.

178. The percentage of BRH material present at the field stations estimated from laboratory exposure-residue relationships for *N. incisa* using the bedded exposure study are shown in Table 17. The general trends in the

percent BRH estimates calculated for the PCBs and the SUM of PAHs are similar. Exposures as percent of BRH in surface sediments from the field also were calculated from analytical data on 0- to 2-cm sediment cores (Table 19). The exposure concentrations calculated from the analytical data give considerably lower percentages of BRH in the surface sediments than those found from estimates using the *N. incisa* residues (Table 22).

Table 22
Comparison of Percentage of BRH Sediment in Field Exposure Sediments
for *N. incisa* at 400E*

<u>Cruise</u>	<u>Percentage Estimated from Exposure-Residue Relationship from Laboratory</u>		<u>Percentage Calculated from Analytical Data from Sediment Samples</u>
	<u>PCBs</u>	<u>PAHs</u>	
T + 2	43	54	12.5
T + 16	60	20	4.9
T + 26	25	16	9.5
T + 44	20	15	1.9
T + 74	17	4.0	0.2

* Station 400E used for comparison purposes.

179. The differences observed in the exposure estimates probably reflect the varied exposure zones in the laboratory and the field for the laboratory bedded exposures. *Nephtys incisa* were exposed to 10 cm of uniformly contaminated BRH sediment mixtures. In the field, predominant exposure to BRH sediment probably resulted from exposure to a very thin (a few millimetres thick) layer of BRH material deposited on the surface of the sediments. Field sediment samples included the thin BRH layer, which was diluted with underlying sediment in the 0- to 2-cm core sections. This dilution of the BRH layer with underlying sediment may have caused the lower BRH exposure estimates calculated from field sediment data (Table 22).

180. Estimates of exposure of *N. incisa* also were made by using the exposure-residue relationship for PCBs in the laboratory suspended exposure studies. With this relationship, PCB tissue residues in field-collected *N. incisa* were used to estimate field BRH exposure concentrations. One of the assumptions in this approach was that tissue residues of PCBs in *N. incisa*

were at a steady-state with respect to the concentration of PCBs in the BRH material at the time of sampling. As mentioned elsewhere, however, the time needed to achieve steady-state PCB concentrations in polychaetes exposed to contaminated sediments has not been established; therefore, it is not known if *N. incisa* from the laboratory studies (42 days exposure to suspended BRH sediments) or from the field were at steady-state with respect to the PCBs in the BRH sediment.

181. The estimated exposures using the above approach are shown in Table 18 as milligrams per litre BRH for each station and *N. incisa* collection date. The highest exposure estimates were for stations near the disposal site for the time periods following the disposal. A drop in exposure in November of 1983 coincided with a storm on 11 and 10 November 1983. It is hypothesized that the surficial sediments at the stations were removed by the storm.

182. Comparisons of these exposure estimates can be made with those from two exposure estimates for suspended exposures. The first calculated maximum upper bound exposures based on the assumption that the suspended solids at the sediment-water interface consist totally of BRH sediment (Table 23). The second exposure estimates for suspended exposure were made using contaminant concentration present in 0- to 2-cm surface sediments after disposal (Table 19). In this approach resuspended surficial sediments are assumed to be the source of contaminants for the suspended sediments. The use of percentages of BRH calculated from the contaminant levels in 0- to 2-cm surface sediments results in adjustment of the maximum upper bound estimates to reflect spatial and temporal changes present at field stations (Table 20). For comparison purposes, exposure estimates from the different methods are shown (Table 23).

183. Exposure estimates from the laboratory suspended study exposure-residue relationship are within the wide range of estimates made for background and storm conditions assuming all suspended material was BRH sediment. The exposure estimates based on the laboratory bioaccumulation study are higher than those calculated from physical and sediment data from the field. We believe this occurred because the 0- to 2-cm field sediment samples contain only a thin layer of highly contaminated BRH sediment with the remainder of the sediment sample consisting of background sediments. The *N. incisa* residues reflect the accumulation from highly contaminated sediments in the thin surficial layer.

Table 23

Comparison of Estimates of Suspended BRH Concentrations (mg/l) at
Sediment-Water Interface at 400E* with Those Made from the
Exposure-Residue Relationship with *N. incisa* from the
Suspended Exposure Laboratory Study

Cruise	Exposure-Residue Relationship from Lab	Range of Estimates Assuming All Suspended Material Was BRH	
		Background Conditions	Sediment Data from Field**
T + 2	95	100 - 10	37.5 - 12.5
T + 6	114		9.9 - 3.3
T + 16	131		14.7 - 4.9
T + 26	51		28.5 - 9.5
T + 44	38		4.7 - 1.9
T + 74	29		0.6 - 0.2

* Station 400E used for comparison purposes.

** Upper estimate represents storm conditions; lower estimate normal conditions.

184. Mixed success occurred in estimating field exposures from (a) laboratory-generated exposure residue correlations and field residue data, and (b) calculations using the available field data. For *M. edulis*, the exposure estimates obtained from (a) and (b) were quite close. However, the exposure estimates from the available water samples represented point-in-time exposure estimates rather than an integrated estimate of exposure over the entire deployment period. For *N. incisa*, comparison of exposure estimates from both (a) and (b) showed the highest BRH exposure occurred shortly after the end of the disposal, and both exposure estimates showed a trend of decreasing exposure in the weeks following disposal. The field exposure estimates from (a) and (b) were not as close for *N. incisa* as they were for *M. edulis*. The lack of agreement for *N. incisa* was probably due to differences in exposure zones between the laboratory and the field, or lack of attainment of true steady-state contaminant concentrations in laboratory and field studies.

Contaminant Accumulation

185. While small differences in the patterns of accumulated PCBs were noticed in the initial phase of the laboratory bioaccumulation studies, the PCB distributions and patterns in both *M. edulis* and *N. incisa* at exposure times at or approaching steady-state were quite similar regardless of the exposure conditions or the exposure sediment. The similarities of PCB distributions and patterns suggest that, for some neutral organic compounds, predictions of the maximum attainable concentrations of contaminants in organisms from a specific dredged material may be made by simply measuring the organic carbon of the material, its concentration of contaminants, and the lipid concentrations of the target organism(s). This view, referred to as "equilibrium partitioning," considers the bioaccumulation of neutral organic contaminants like PCBs to be part of a redistribution of contaminants between the organic carbon of the sediments (the source) and the lipids of the organism (the sink) (MacKay and Patterson 1981; McFarland 1984; Karickhoff and Morris 1986; Lake, Rubinstein, and Pavignano 1986). The PCB distributions in the organisms are altered from those in the source (sediment) by barriers or processes that impact the compound's availability from the sediment and/or the accumulation or retention of the compound in the organism.

186. For compounds like PCBs, which are associated with the organic carbon of the sediments and are resistant to metabolic breakdown, the distributions and patterns in organisms are determined by the partitioning of contaminants and the impact of kinetic and steric barriers on those distributions (Tulp and Hutzinger 1978).

187. Other neutral compounds like PAHs: (a) have a greater range of physical-chemical properties than PCBs, which results in their being more dynamic in bioaccumulation studies; (b) are metabolized by organisms; and (c) may not be as available from sediments as PCBs. PAHs are metabolized by organisms, and their uptake and depuration by organisms are more rapid than for many PCB compounds. This issue of PAH availability and accumulation is further complicated because of differences in the distributions and availability of PAHs from combustion sources and petroleum, which are the two major inputs of PAHs to the environment (Hase and Hites 1976; Hites 1976; Lake et al. 1979).

188. PAH patterns from combustion sources show a greater abundance of

parent compounds relative to alkyl homologs. The relative proportion of each compound type is dependent on the fuel used and the combustion temperature. These PAHs may be transported to the environment in or on soot particles where some of the PAH compounds may be physically unavailable. Petroleum sources of PAH compounds generally have a lower molecular weight distribution and a much higher ratio of alkyl homologs relative to parent PAHs than combustion sources. Considering the differences in PAH properties, sources, and availability, it is not surprising to find irregularities in their accumulation curves for laboratory exposure studies, and differences in the patterns of PAHs accumulated in organisms from the laboratory and the field exposures.

PART V: CONCLUSIONS

189. This research was designed to evaluate the use of laboratory tests for predicting bioaccumulation of contaminants in the field by comparing the identities, relative abundances, and quantities of organic and inorganic contaminants accumulated by organisms exposed to dredged material in both laboratory and field studies. The following are conclusions from the study:

- a. The laboratory methods that were developed for exposure of *M. edulis* to suspended sediments were found to maintain constant concentrations of total suspended sediment and the proper ratio of contaminated dredged material and reference sediment.
- b. In the laboratory, contaminant uptake patterns in *M. edulis* were directly related to BRH suspended sediment concentrations. The tissue residue values for PCBs, when corrected for organism lipid content, were linearly related to contaminant concentration. Tissue residues reached steady-state for PCBs and PAHs within 28 days.
- c. Laboratory methods were developed to expose the infaunal polychaete *N. incisa* to contaminated dredged material through both suspended and bedded sediment exposures. Tissue residues in both exposures increased with increased exposure to BRH sediment. Tissue residues of PAHs appeared to reach steady-state, but PCBs did not reach steady-state in the 55-day bedded sediment experiments. Tissue residue values for PCBs and PAHs reached an apparent steady-state during the 42 days exposure to suspended sediment.
- d. Evaluation of the utility of compounds for examining the relationship between tissue residues in the laboratory and field with *M. edulis* and *N. incisa* showed that, in general, PCBs were the most useful compounds. PCBs showed the best relationship between laboratory and field for residue patterns and concentrations in both *M. edulis* and *N. incisa*.
- e. Careful consideration must be given to the organism(s) selected for laboratory bioaccumulation tests. This consideration should include the available knowledge on feeding modes for these organisms so that exposure zones can be established and exposure-residue relationships can be determined. Further, the spawning habits and associated changes in lipid concentrations of the organisms must be accounted for in the experimental design since these factors are known to impact bioaccumulation. Finally, organism selection must be coupled with the overall objectives and capabilities of the study.
- f. Long-term (months to years) laboratory bioaccumulation research studies should be conducted to determine the extent of bioaccumulation of contaminants by organisms exposed to contaminated sediments. The PCB residue concentrations in

N. incisa did not appear to reach steady-state in the 55-day bioaccumulation test. These findings suggest that laboratory exposure experiments with some organisms may need to run for extended time periods (months to years) to allow assessment of long-term bioaccumulations. Knowledge of the maximum concentration attainable will aid in development of shorter term tests to assess bioaccumulation potential of sediment-associated contaminants.

- g. Further research to examine the utility of the equilibrium partitioning approach for estimating the maximum concentration of some neutral organic contaminants (like PCBs) that can be bioaccumulated from a specific dredged material should be done. The similarities of the distributions and patterns of PCBs in organisms from the laboratory and field exposures in this study suggest that similar processes govern these distributions. The development of a first tier test to estimate the maximum residue concentrations would be of great assistance for facilitating disposal decisions.

REFERENCES

- American Society for Testing and Materials. 1982. Proposed Standard Practice for Conducting Bioconcentration Tests with Fishes and Saltwater Bivalve Molluscs, Draft 5, Philadelphia, Pa.
- Bohlen, W. F., and Winnick, K. B. 1986. "Observations of Near-Bottom Suspended Material Concentrations at the FVP Site, Central Long Island Sound Dredged Materials Area: Immediate Predisposal, Disposal and Immediate Post-disposal Period, April 18, 1983 - June 29, 1983," Prepared by Science Applications International Corporation, Newport, R. I., by Marine Sciences Institute, Groton, Conn.
- Boyle, E. A., and Edmond, J. M. 1975. "Determination of Trace Metals in Aqueous Solution by APDC Chelate Co-precipitation," Analytical Methods in Oceanography, American Chemical Society Publication, pp 44-55.
- Bysse, S. E. 1982. "Bioaccumulation Factor in Aquatic Organisms," Handbook of Chemical Estimation Methods, W. J. Lyman, W. F. Reehl, and D. H. Rosenblatt, eds., McGraw-Hill, New York, pp 5-1 - 5-30.
- Davey, E. W., Gentile, J. H., Erickson, S. J., and Betzer, P. 1970. "Removal of Trace Metals from Marine Culture Media," Limnology and Oceanography, Vol 15, pp 486-488.
- Ediger, R. D., Peterson, G. E., and Kerber, J. D. 1974. "Application of the Graphite Furnace to Saline Water Analysis," Atomic Absorption Newsletter, Vol 13, p 61.
- Fernandez, F. J., and Giddings, R. 1982. "Elimination of Spectral Interferences Using Zeeman Effect Background Correction," Atomic Spectroscopy, Vol 3, pp 61-65.
- Fernandez, F. J., Meyers, S. A., and Slavin, W. 1980. "Background Correction in Atomic Absorption Utilizing the Zeeman Effect," Analytical Chemistry, Vol 52, pp 741-746.
- Fowler, G. W., Polikarpov, Y. G., Elder, D. L., Parsi, P., and Villeneuve, J. P. 1978. "Polychlorinated Biphenyls Accumulation from Contaminated Sediments and Water by the Polychaete *Nereis diversicolor*," Marine Biology, Vol 48, pp 303-309.
- Galloway, W. B., Lake, J. L., Phelps, D. K., Rogerson, P. F., Bowen, V. T., Farrington, J. W., Goldberg, E. D., Lasiter, J. L., Lawler, G. C., Martin, J. H., and Risebrough, R. W. 1983. "The Mussel Watch: Intercomparison of Trace Level Constituent Determinations," Environmental Toxicology and Chemistry, Vol 2, pp 395-410.
- Gentile, J. H., and Scott, K. J. 1986. "The Application of a Hazard Assessment Strategy to Sediment Testing: Issues and Case Study," Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems, K. L. Dickson, A. W. Maki, and W. Brungs, eds., SETAC Special Publication, pp 1-17.
- Hase, A., and Hites, R. A. 1976. "On the Origin of Polycyclic Aromatic Hydrocarbons in the Aqueous Environment," Identification and Analysis of Organic Pollutants in Water, H. L. Keith, ed., Ann Arbor, pp 205-214.

Hites, R. A. 1976. "Sources of Polycyclic Hydrocarbons in the Aquatic Environment," Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment, American Institute of Biological Science, pp 325-333.

Karickhoff, S. W., and Morris, K. R. 1986. "Pollutant Sorption: Relationship to Bioavailability," Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems, K. L. Dickson, A. W. Maki, and W. Brungs, eds., Proceedings of Sixth Pellston Workshop, August 1984, Florissant Colo.

Lake, J., Hoffman, G. L., and Schimmel, S. C. 1985. "The Bioaccumulation of Contaminants from Black Rock Harbor Material by Mussels and Polychaetes," Technical Report D-85-2, prepared by the US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Lake, J. L., Norwood, C., Dimock, C., and Bowen, R. 1979. "Origins of Polycyclic Aromatic Hydrocarbons in Estuarine Sediments," Geochimica et Cosmochimica Acta, Vol 43, pp 1847-1854.

Lake, J. L., Rubinstein, N., and Pavignano, S. 1986. "Predicting Bioaccumulation: Development of a Simple Partitioning Model for Use as a Screening Tool for Regulating Ocean Disposal of Wastes," Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems, K. L. Kickson, A. W. Maki, and W. Brungs, eds., Proceedings of Sixth Pellston Workshop, August 1984, Florissant, Colo.

Laxen, D. P. H., and Harrison, J. 1981. "Cleaning Methods for Polyethylene Containers Prior to the Determination of Trace Metals in Freshwater Samples," Analytical Chemistry, Vol 53, pp 345-350.

Mackay, D., and Patterson, S. 1981. "Calculating Fugacity," Environmental Science and Technology, Vol 15, pp 1006-1014.

McFarland, V. A. 1984. "Activity-Based Evaluation of Potential Bioaccumulation for Sediments," Dredging and Dredged Material Disposal, Vol 1, R. L. Montgomery and J. W. Leach, eds., American Society of Civil Engineers, New York, pp 461-467.

McLeese, D. W., Metcalfe, C. D., and Pezzack, D. S. 1980. "Uptake of PCBs from Sediment by *Nereis virens* and *Crangon septemspinosa*," Archives of Environmental Contamination and Toxicology, Vol 9, pp 507-518.

Moody, J. R. 1982. "NBS Clean Laboratories for Trace Element Analysis," Analytical Chemistry, Vol 54, No 13, pp 1358-1376.

Munns, W. R., Paul, J. F., Bierman, V. J., Jr., Davis, W. R., Galloway, W. B., Hoffman, G. L., Rogerson, P. F., and Pruell, R. J. 1986. "Exposure Assessment Component of the Field Verification Program: Data Presentation and Synthesis," Contribution 751, US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I.

Murphy, T. J. 1976. "The Role of the Analytical Blank in Accurate Trace Analysis," Accuracy in Trace Analysis: Sampling, Sample Handling, Analysis, Proceedings of the Seventh Materials Research Symposium, US Government Printing Office, Washington, DC, pp 509-539.

Patterson, C. C., and Settle, D. M. 1976. "The Reduction of Orders of Magnitude Errors in Lead Analysis of Biological Materials and Natural Waters by Evaluating and Controlling the Extent and Sources of Industrial Lead Contamination Introduced During Sample Collecting, Handling, and Analysis,"

Accuracy in Trace Analysis: Sampling, Sample Handling, and Analysis, Proceedings of the Seventh Materials Research Symposium, US Government Printing Office, Washington, DC, pp 321-351.

Pesch, G. G., et al. 1987. "Sister Chromatid Exchange in Marine Polychaetes Exposed to Black Rock Harbor Sediment," Technical Report D-87-5, prepared by the US Environmental Protection Agency, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Rogerson, P. F., Schimmel, S. C. and Hoffman, G. L. 1985. "Chemical and Biological Characterization of Black Rock Harbor Dredged Material," Technical Report D-85-9, prepared by the US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Rubinstein, N. I., Lores, E., and Gregory, N. R. 1983. "Accumulation of PCBs, Mercury, and Cadmium by *Nereis virens*, *Mercenaria mercenaria*, and *Palaemonetes pugio* from Contaminated Harbor Sediments," Aquatic Toxicology, Vol 3, pp 249-260.

Rugg, T., and Feldman, P. 1980. "Mathematics Programs," TRS-80 Programs, Section 5, Dilithium Press, Forest Grove, Oreg., pp 185-194.

SAS. 1985. "SAS User's Guide: Statistics Version," 5th ed., SAS Institute, Gary, N. C.

Sinnett, J. C., and Davis, W. R. 1983. "A Programmable Turbidistat for Suspended Particles in Laboratory Aquaria," Journal of Experimental Marine Biology and Ecology, Vol 73, pp 167-174.

Slavin, W. 1980. "The Determination of Trace Metals in Seawater," Atomic Spectroscopy, Vol 1, pp 66-71.

Snedecor, G. W., and Cochran, W. G. 1967. Statistical Methods, Iowa State University Press, Iowa.

Sturgeon, R. E., Berman, S. S., Desauiniers, A., and Russell, D. S. 1979. "Determination of Iron, Manganese, and Zinc in Seawater by Graphite Furnace Atomic Absorption Spectrometry," Analytical Chemistry, Vol 51, pp 2364-2369.

Tulp, M. T. M., and Hutzinger, O. 1978. "Some Thoughts on Aqueous Solubilities and Partition Coefficients of PCB and the Mathematical Correlation Between Bioaccumulation and Physio-Chemical Properties," Chemosphere, Vol 7, pp 849-860.

US Environmental Protection Agency/US Army Corps of Engineers. 1977. "The Ecological Evaluation of Proposed Discharge of Dredged Material into Ocean Waters: Implementation Manual for Section 103 of PL 92-532," Environmental Effects Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

US Environmental Protection Agency. 1979. "Methods for Chemical Analysis of Water and Wastes," EPA/600-4-79-020, US Environmental Monitoring and Support Laboratory, Office of Research and Development, Cincinnati, Ohio.

APPENDIX A: BLACK ROCK HARBOR (BRH) SEDIMENT PERCENTAGE CALCULATIONS

Table A1
Percentage of BRH Sediment in the Surficial Sediments (0-2 cm)
and the Contaminants Used for the Percent Calculations

Date	Station			Percentage of BRH Sediment
	CNTR	200E	400E	
Jun 1983	44.5	41.1	12.5	1.8
Ju1 1983	15.0	37.4	3.3	1.6
Sep 1983	32.0	36.7	4.9	2.0
Dec 1983	32.8	36.1	9.5	4.4
Mar 1984	4.4	2.2	1.9	1.8
Jun 1984	9.5	15.6	0.5	0.7
Sep 1984	10.0	0.8	3.5	0.5
Oct 1984	2.6	--	0.2	1.6
Dec 1984	35.1	11.3	0.0	1.0
Oct 1985	0.2	21.0	0.0	0.0

(Continued)

Table A1 (Concluded)

Date	Station			Contaminants Used
	CNTR	200E	400E	
Jun 1983	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	Cd+Cu+Cr
Jul 1983	PAH+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Sep 1983	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Dec 1983	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr
Mar 1984	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Jun 1984	Cd+Cu+Cr	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr
Sep 1984	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr	PAH+PCB+Cd+Cu+Cr
Oct 1984	PAH+PCB	--	PAH+PCB	PAH+PCB
Dec 1984	Cd+Cu+Cr	Cd+Cu+Cr	Cu+Cr	Cu+Cr
Oct 1985	PCB	PAH+PCB	PCB	PAH+PCB

Table A2

Phenanthrene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	114
12/8/82	--	--	--	--	77
3/2/83	105	101	132	--	107
3/2/83	--	--	--	--	98
3/2/83	--	--	--	--	62
6/3/83	1,560	1,960	910	52	88
6/3/83	--	--	--	63	--
7/26/83	770	1,710	240	174	51
9/1/83	780	1,010	220	168	94
9/1/83	--	--	--	--	81
3/19/84	77	98	100	250	42
3/20/84	--	--	141	78	90
3/20/84	--	--	--	--	76
3/20/84	200	--	--	--	--
9/11/84	147	57	116	109	40
10/16/84	230	--	85	137	123
10/22/85	43	440	38	69	51

Table A3

178 Alkyl Homolog Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	210
12/8/82	--	--	--	--	172
3/2/83	250	210	260	--	188
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	127
6/3/83	11,000	10,000	5,300	230	189
6/3/83	--	--	--	122	--
7/26/83	9,700	13,000	1,500	412	131
9/1/83	5,200	12,000	1,480	613	186
9/1/83	--	--	--	--	189
3/19/84	1,330	590	560	600	103
3/20/84	--	--	590	260	170
3/20/84	--	--	--	--	185
3/20/84	1,200	--	--	--	--
9/11/84	3,000	270	640	250	103
10/16/84	1,260	--	240	420	240
10/22/85	490	3,800	430	210	192

Table A4

Fluoranthene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	200
3/2/83	300	260	340	--	270
3/2/83	--	--	--	--	230
3/2/83	--	--	--	--	148
6/3/83	2,300	2,300	1,240	142	220
6/3/83	--	--	--	161	--
7/26/83	1,940	2,600	570	400	140
9/1/83	1,370	2,800	560	380	220
9/1/83	--	--	--	--	210
3/19/84	290	330	330	600	124
3/20/84	--	--	360	210	230
3/20/84	--	--	--	--	185
3/20/84	510	--	--	--	--
9/11/84	650	166	410	250	108
10/16/84	580	--	240	320	300
10/22/85	172	1,770	142	196	189

Table A5
Benzo(a)pyrene Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	280
12/8/82	--	--	--	--	220
3/2/83	260	270	310	--	220
3/2/83	--	--	--	--	210
3/2/83	--	--	--	--	173
6/3/83	1,640	1,490	810	122	210
6/3/83	--	--	--	158	--
7/26/83	1,520	1,750	380	370	169
9/1/83	1,000	2,100	570	320	200
9/1/83	--	--	--	--	230
3/19/84	220	350	260	450	155
3/20/84	--	--	400	280	240
3/20/84	--	--	--	--	185
3/20/84	460	--	--	--	--
9/11/84	600	230	400	260	111
10/16/84	450	--	240	320	290
10/22/85	280	1,130	230	196	380

Table A6

SUM PAH Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	5,200
12/8/82	--	--	--	--	4,500
3/2/83	5,100	4,900	5,900	--	4,400
3/2/83	--	--	--	--	4,300
3/2/83	--	--	--	--	3,300
6/3/83	62,000	59,000	30,000	2,400	3,900
6/3/83	--	--	--	3,000	--
7/26/83	54,000	63,000	10,100	7,200	3,200
9/1/83	33,000	71,000	13,500	7,200	3,600
9/1/83	--	--	--	--	4,300
3/19/84	7,200	7,100	6,200	9,300	2,700
3/20/84	--	--	7,300	4,500	3,600
3/20/84	--	--	--	--	4,300
3/20/84	11,100	--	--	--	--
9/11/84	18,600	4,400	8,600	5,000	2,000
10/16/84	11,500	--	4,800	6,700	5,800
10/22/85	5,400	34,000	4,900	3,800	5,400

Table A7
Centroid Statistic in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	249.7
12/8/82	--	--	--	--	252.0
3/2/83	247.6	248.9	247.7	--	247.4
3/2/83	--	--	--	--	248.0
3/2/83	--	--	--	--	252.1
6/3/83	238.7	234.1	235.2	241.4	248.3
6/3/83	--	--	--	250.3	--
7/26/83	234.7	232.6	234.4	247.3	252.5
9/1/83	239.7	238.6	244.7	244.3	245.4
9/1/83	--	--	--	--	250.3
3/19/84	237.0	245.1	241.1	244.5	251.0
3/20/84	--	--	243.5	245.3	243.7
3/20/84	--	--	--	--	251.5
3/20/84	242.9	--	--	--	--
9/11/84	240.8	249.2	244.1	247.5	247.2
10/16/84	240.4	--	248.4	247.7	250.0
10/22/85	248.8	241.1	248.6	248.7	253.4

Table A8

Ethylan Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>40GE</u>	<u>1000E</u>	
8/18/82	--	--	--	--	--
11/11/82	--	--	--	--	--
12/8/82	--	--	--	--	0.0
12/8/82	--	--	--	--	0.0
3/2/83	0.0	0.0	0.0	--	0.0
3/2/83	--	--	--	--	0.0
3/2/83	--	--	--	--	0.0
6/3/83	340.0	370.0	163.0	5.0	0.0
6/3/83	--	--	--	0.0	--
7/26/83	0.0	950.0	90.0	35.0	0.0
9/1/83	210.0	670.0	30.0	15.0	0.0
9/1/83	--	--	--	--	0.0
3/19/84	74.0	50.0	36.0	31.0	0.0
3/20/84	--	--	12.0	0.0	0.0
3/20/84	--	--	--	--	0.0
3/20/84	23.0	--	--	--	--
9/11/84	96.0	14.0	64.0	3.0	0.0
10/16/84	12.0	--	2.0	7.0	0.0
10/22/85	8.0	820.0	4.0	5.0	0.0

Table A9
PCB (A1254) Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				<u>REFS</u>
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	
8/18/82	--	--	73	--	59
11/11/82	--	--	30	--	26
12/8/82	--	--	--	--	48
3/2/83	77	75	98	--	65
3/2/83	--	--	--	--	67
3/2/83	--	--	--	--	60
6/3/83	1,730	1,650	890	79	59
6/3/83	--	--	--	45	--
7/26/83	180	1,830	240	117	28
9/1/83	1,190	2,200	340	200	59
3/19/84	270	250	162	96	26
3/20/84	181	--	--	--	--
9/11/84	440	113	183	66	27
10/16/84	181	--	84	162	77
10/22/85	72	1,150	37	48	29

Table A10
Cadmium Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	0.36	0.34	1.06	0.29	0.24
3/4/83	0.39	0.35	0.44	0.21	0.22
3/4/83	0.35	0.49	0.32	0.25	0.22
6/3/83	17.00	13.90	7.30	0.74	0.22
6/3/83	12.40	14.70	4.20	0.58	0.21
6/3/83	13.00	12.90	3.70	0.64	0.19
7/26/83	5.40	11.70	1.14	0.64	0.22
9/1/83	4.10	9.80	0.84	0.68	0.18
9/1/83	21.00	8.70	3.60	0.76	--
12/9/83	8.80	8.70	3.30	1.02	--
3/19/84	2.10	1.11	0.85	1.08	0.20
3/19/84	--	0.87	--	--	--
3/19/84	--	0.23	--	--	--
6/12/84	3.10	4.80	0.37	0.39	--
9/11/84	3.70	0.73	0.97	0.30	0.20
12/20/84	9.30	2.50	0.32	0.72	--
10/22/85	0.45	8.30	0.29	0.32	0.16

Table All
Chromium Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	56	39	59	59	48
3/4/83	53	57	43	58	52
3/4/83	45	56	56	60	54
6/3/83	870	680	340	69	49
6/3/83	780	740	191	72	48
6/3/83	800	600	155	74	48
7/26/83	120	519	69	66	44
9/1/83	310	600	106	79	56
9/1/83	680	380	160	79	--
12/9/83	520	660	117	126	--
3/19/84	100	52	54	86	47
3/19/84	--	140	--	--	--
3/19/84	--	40	--	--	--
6/12/84	138	210	41	52	--
9/11/84	153	41	128	55	44
12/20/84	550	175	47	88	--
10/22/85	54	430	57	59	40

Table A12
Copper Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	67	57	67	70	55
3/4/83	62	69	63	68	57
3/4/83	63	67	64	69	58
6/3/83	1,640	1,380	680	99	48
6/3/83	1,300	1,420	360	102	51
6/3/83	1,330	1,240	303	106	56
7/26/83	450	1,230	185	106	49
9/1/83	560	1,070	134	103	47
9/1/83	1,890	910	510	122	--
12/9/83	910	950	370	177	--
3/19/84	200	111	143	123	53
3/19/84	--	107	--	--	--
3/19/84	--	114	--	--	--
6/12/84	350	530	89	83	--
9/11/84	430	86	156	73	48
12/20/84	1,000	500	52	131	--
10/22/85	92	910	75	72	46

Table A13

Iron Concentrations (ng/g Dry Weight) in Surficial Sediments

<u>Date</u>	<u>Station</u>				
	<u>CNTR</u>	<u>200E</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
3/4/83	21,000	17,100	22,000	23,000	19,700
3/4/83	20,000	22,000	18,900	23,000	21,000
3/4/83	18,400	21,000	21,000	23,000	22,000
6/3/83	17,100	19,200	23,000	21,000	21,000
6/3/83	19,300	19,000	22,000	21,000	19,000
6/3/83	17,900	18,700	23,000	22,000	21,000
7/26/83	15,200	16,700	21,000	16,800	21,000
9/1/83	15,100	19,300	21,000	18,400	19,700
9/1/83	26,000	15,100	--	16,400	--
12/9/83	16,500	21,000	19,600	17,500	--
	5,800				
3/19/84	--	17,300	20,000	18,700	21,000
3/19/84	--	16,600	--	--	--
3/19/84		15,600	--	--	--
6/12/84	6,500	17,100	19,800	15,600	--
9/11/84	12,600	17,400	18,400	18,200	21,000
12/20/84	18,100	17,300	17,400	18,000	--
10/22/85	9,900	17,200	18,100	18,900	17,000

APPENDIX B: CHEMICAL METHODS

Organic Samples

Sample preparation

1. Cleaning of glassware and equipment. All glassware used for the collection storage, extraction, and analysis of samples was washed with Alconox®, rinsed four times with hot tap water, rinsed four times with de-ionized water, capped with aluminum foil, and muffled for 6 hr at 450° C. Immediately prior to use, glassware was rinsed three times with an appropriate solvent.

2. Sediment. The methods that follow were used for the extraction and analysis of Black Rock Harbor (BRH) sediment and the reference sediment from the worm dosing system and for analyses of sediments collected in the field. Approximately 15 g of wet sediment was placed in a stainless steel centrifuge tube, and 25 ml of acetone was added. The mixture was homogenized for 40 sec using a Polytron (Brinkman Corp.) equipped with a stainless steel tip and brass-bearing and then centrifuged at 70,000 rpm for 5 min at 4° C. The acetone was decanted into a 1-ℓ separatory funnel containing 150 ml of pre-extracted deionized water. The extraction and centrifugation steps were repeated once more with acetone and the extract added to the separatory funnel. This procedure was repeated twice more using Freon 113 instead of acetone, and the Freon extracts were also added to the separatory funnel. The funnel was shaken, and the Freon layer was drawn off into a 500-ml Erlenmeyer flask. This partitioning was repeated two more times using 50 ml of Freon each time. The extracts were combined in the Erlenmeyer flask. the sample extract was then subjected to column chromatography.

3. Water. The following procedure was used for unfiltered water sample from the field and from the laboratory. Six 1-gal containers (22.7 ℓ total) of seawater were analyzed for each whole water sample collected in the field. Approximately 100 ml of methylene chloride was added to each container at the time of collection. Water from each container and the methylene chloride previously added were poured into a 6-ℓ separatory funnel for extraction. Additional methylene chloride was added to bring the solvent volume to 250 ml, and the separatory funnel was shaken vigorously. The extract was allowed to settle and then drawn off into an Erlenmeyer flask. One hundred millilitres of methylene chloride was added to the funnel and the process computed. This was done for each of the six bottles, and the extracts were combined. Sodium

sulfate (previously muffled at 700° C for 4 hr) was added to remove water.

4. The Freon extract was poured off and volume reduced in a round bottom flask fitted with a Kuderna-Danish evaporator, and the solvent was changed to hexane. Extracts (5 ml) were fractionated using the second silicic acid column (see paragraph 7).

5. Organisms. Shucked mussel or worm samples were homogenized using a polytron with Teflon bearings for 20 sec. A portion of the sample (approximately 2 g) was removed for determination of a wet-to-dry ratio, and another portion (approximately 2 g) was taken for inorganic analysis. Approximately 15 to 20 g of the homogenate was added to a preweighed glass centrifuge tube, and the weight was recorded.

6. Each of the sample homogenates was treated as a separate sample with appropriated blanks carried through the entire procedure. To each sample was added 15 ml of acetone; the mixture was then homogenized with a tissue homogenizer for 20 sec and centrifuged at 2,500 rpm for 5 min at 4° C. The fluid layer was decanted into a separatory funnel containing 150 ml of pre-extracted, deionized water. The acetone extractions and centrifugation were repeated once more, and the extracts were combined in the separatory funnel. The tissue homogenization, extraction, and centrifugation were repeated twice more using 25 ml of Freon 113 as the solvent. Because of the density of the Freon, the solvent was withdrawn from the bottom of the centrifuge tubes using a syringe. The Freon extracts were combined in the separatory funnel, which was then shaken, and the Freon layer was drawn off and saved. The remaining aqueous layer was extracted twice more with 50 ml of Freon each time. The Freon extracts were combined, and the aqueous layer was discarded. The sample extract was then subjected to column chromatography.

Column chromatography,
volume reduction, and storage

7. To remove interfering biogenic material and some residual particulates, the combined Freon extracts were passed through the first column (2 by 25 cm of 100-percent activated 100-200 mesh silicic acid). For sediment samples, 2.5 cm of activated copper powder was added to the bottom of the first column to remove elemental sulfur. The column was then rinsed with 25 ml of Freon followed by 50 ml of methylene chloride. The eluate was collected and volume reduced in a round bottom flask fitted with a Kuderna-Danish evaporator and 3-ball Snyder column. The solvent was exchanged to hexane as the sample

approached 5 ml. Final volume reduction to 5 ml was accomplished by placing the sample in a concentrator tube fitted with a micro-Snyder column and placing it into a tube heater.

8. The 1-ml sample extracts were then charged into a 0.9- by 45-cm second column of 5-percent water deactivated 100-200 mesh silicic acid which had been rinsed with 50 ml of methylene chloride and 50 ml of pentane. Three fractions were collected from the column. Fraction 1 (PF-50) consisted of 50 ml of pentane, fraction 2 (F-2) consisted of 35 ml of 20-percent methylene chloride in pentane, and fraction 3 (F-3) consisted of 35 ml of methylene chloride. The PF-50 fraction is an expansion of the first fraction formerly used by this laboratory. The PF-50 fraction is designed to include polychlorinated biphenyls (PCBs) and related chlorinated pesticides of similar polarity in addition to the petroleum hydrocarbons. The polycyclic aromatic hydrocarbons (PAHs) were collected in the F-2 fraction. The F-3 fraction contained more polar material. Each column fraction was reduced in volume by Kuderna-Danish evaporation as above, with the solvent changed to hexane. The final sample volume of 1 ml was achieved by adding 1 ml of heptane to the sample in a 10-ml concentrator tube. Glass ebullators, micro-Snyder columns, and a tube heater were utilized to reduce the sample to 1 ml. The extracts were then divided in half between sealed glass ampules for archival storage and screw cap vials for gas chromatographic and gas chromatograph/mass spectrometric (GC/MS) analyses.

Organic instrumental analysis

9. Electron capture gas chromatographic analyses were conducted on a Hewlett-Packard Model 5840 gas chromatograph equipped with a 30-m DB-5 fused silica capillary column from J&W. The chromatograph was temperature programmed from 80° C to 290° C at 10° C/min with a 4-min hold at 80° C. The injector temperature was 270° C, and the detector was maintained at 300° C. Flame ionization gas chromatographic analyses were conducted on a Carlo Erba 4160 chromatograph equipped with an identical column. The temperature was programmed from 60° C to 325° C at 10° C/min with a 4-min hold at 60° C. The injector temperature was 275° C, and the detector was maintained at 335° C.

10. GC/MS analyses were conducted on a Finnigan Model 4500 also equipped with J&W DB-5 30-m fused silica capillary column. The tail of the capillary column was positioned inside the mass spectrometer so that the

effluent from the column was directed into the ionization volume of the mass spectrometer. The mass spectrometer was operated through a standard Inco data system and was tuned at all times to meet US Environmental Protection Agency (USEPA) quality assurance specifications using decafluorotriphenylphosphine. The ionizing current was typically set at 300 mA and 70 eV, and the instrument operated such that 100 pg of PAHs from naphthalene to benzo-pyrene gave easily quantifiable signals on their molecular ions with signal-to-noise ratios of 50:1 or better. The mass spectrometer's gas chromatograph was typically programmed from 50° C to 330° C at 10° C/min with a 2-min hold at 50° C, but was occasionally programmed at 4° C/min to permit higher chromatographic resolution.

11. All instruments were calibrated with standards each day. The concentrations of the standards used were chosen to be close to the levels of the materials of interest, and periodic linearity checks were made to ensure the proper performance of each system. When standards were not available for some compounds, response factors were calculated using mean responses of appropriate standards.

12. In this report, PCBs were quantified as Aroclor 1254 (A1254) by measuring and summing the peak heights of seven representative peaks in Electron Coptone Detector (ECD) gas chromatograms. PCBs, as used in this report, refer to the A1254 concentration determined by this technique.

Inorganic Samples

Sample preparation

13. Sediment. Frozen sediment samples were thawed and then homogenized by stirring with a stainless steel spatula. Frozen sediment core samples were partially thawed, sectioned, homogenized, and then subsampled for analysis. Each core sample (previously stored at -20° C) was held in a refrigerator maintained at 3° C for 8 to 9 hr prior to sectioning. This technique of slowly warming the core samples allowed sectioning to be done without complete thawing. The core samples were placed on a piece of aluminum foil (muffled at 450° C for 6 hr) and incrementally pushed (2 cm at a time) out of the core liner. Each 2-cm increment was cut with a stainless steel spatula and transferred to an acid-cleaned and muffled (450° C for 6 hr) glass container. Each container was labeled with a unique sample number that indicated the core

number and section. To avoid cross-contamination of the core sections during the cutting process, the spatula was washed with deionized water after each cut. At least five sections (2 cm length) could be cut from each core. A sixth section of varying length was obtained from several of the cores. The sections were then thawed completely and homogenized by stirring with the spatula. Aliquots of the wet sediment (approximately 5 g) were transferred to tared, 60-ml, acid-cleaned, polyethylene bottles. Replicate aliquots of several of the core sections were taken to determine the precision of the methodology used to cut and mix the sediment. The wet weights of all samples were then determined. The sample aliquots were frozen again and then freeze dried in a Virtis lyophilizer Model #10--145MR-BA for 2 days. The dry weight of each sample was then determined. The dried sediment samples were acidified with 50 ml of 2N HNO₃ (reagent grade), sealed with a polyethylene screw cap, and then stored at room temperature for 2 days. During the storage period the samples were vented daily to prevent rupturing the plastic containers. After venting, the samples were mildly shaken to resuspend the sediment in the closed containers. The samples were then gravity filtered through acid-washed (2N HNO₃) Whatman 42 filter paper into 60-ml, acid-cleaned polyethylene bottles so that the insoluble residue would not interfere with the subsequent atomic absorption analysis. A measured portion of each sample (1 to 5 ml) was treated with 30-percent H₂O₂ to oxidize soluble organic surface active components that passed through the Whatman filter. Generally 1 ml of peroxide was added to each millilitre of subsample taken for analysis. This oxidation was necessary if the sample in question was analyzed by heated graphite atomization atomic absorption (HGA-AA) for any of the elements determined in this study.

14. Seawater. All tasks involving the preparation of seawater samples for trace metal analysis, including container cleaning and reagent preparation, were performed in a class 100 clean room. This clean room was specially modified to be free of exposed metal surfaces (Moody 1982, Murphy 1976, Paterson and Settle 1976*). Containers used in collection, storage, and coprecipitation were soaked for 48 hr in heated (53° C) 2N HNO₃, 24 hr in heated deionized (DI) water, followed by a second rinse in heated DI water (Laxen and Harrison 1981). Vials of 1 and 6 ml and disposable pipette tips were cleaned

* See References at the end of the main text.

with concentrated HNO_3 (heated) and rinsed in the above manner. The water bath was made of polyethylene, and the heating elements and thermostat sensor were Teflon jacketed.

15. Following shipboard separation of the seawater particulate fractions, filter samples were dried in a laminar flow, class 100 clean bench and weighed. Filters were placed into a 6-ml polyethylene vials along with 5 ml of 2 HNO_3 for an effective concentration factor of 50. Dissolution was enhanced by maintaining the sample vials in a sonicated water bath for a minimum of 24 hr. The samples were stored for later analysis by atomic absorption.

16. No chemical separation was used to prepare iron for whole water seawater samples prior to analysis by atomic absorption. Subsamples of 1 ml (three to five replicates of each sample) were simply pipeted into 1.2-ml polyethylene vials (acid cleaned). To each 1-ml sample was added 100 μl of concentrated Ultrex HNO_3 . The vials were fitted with snap caps and stored for later analysis by atomic absorption.

17. Copper and Cadmium were separated and concentrated from the seawater for both the whole water and soluble fractions with a coprecipitation technique. The coprecipitation technique was described by Boyle and Edmond (1975).

18. Mytilus. All metal data reported for mussel samples from a given location are the average of three composite samples of five individual mussels. The 15 mussels analyzed were selected at random from a station/date collection bag. The frozen mussels were partially thawed prior to being shucked. All the instruments used in shucking the mussels were stainless steel. As a precaution against cross-contamination, the instruments used in shucking were cleaned between samples by rinsing with deionized water. The mussel meat and frozen shell liquor were shucked into tared, acid-cleaned, 250-ml Pyrex beakers and covered with Pyrex watch glasses. The wet weight was recorded prior to drying the samples. The samples were oven dried to constant weight at 95° C, and then stored in a desiccator until attaining room temperature. The dry weights were then determined. Dry mussel samples were decomposed with 100 ml of concentrated HNO_3 (reagent grade), which was added in 20-ml aliquots over a period of 2 days. Samples were allowed to cold digest during the period of acid addition. Mussel tissue was well broken down before gentle heat was applied. Samples were then slowly heated to just below their boiling point (approximately 60° C) and maintained at that temperature for

8 hr. This process was repeated over the course of several days. The samples were then evaporated to incipient dryness and removed from the hot plate. Each sample residue was reconstituted with 20 ml of 2 HNO_3 and filtered through acid-washed Whatman #42 filter paper into a 50-ml volumetric flask. Each sample beaker was rinsed out with several 10- to 15-ml portions of 5-percent HNO_3 . These washings were also sent through the filter and combined with the initial solution. The final sample solution was brought to 50 ml by the addition of 2 HNO_3 . The sample solutions were then poured into 60-ml, acid-cleaned, polyethylene bottles and stored for later analysis.

19. An aliquot (5 ml) of the sample solution was oxidized with hydrogen peroxide (30 percent) to destroy surface active soluble organic compounds that passed through the filter.

20. Nephtys. The individual worm samples contained in the tared, labeled vials were weighed and then freeze dried in a Virtis lyophilizer until constant weight (ca. 2 days) was obtained. One millilitre of concentrated nitric acid (reagent grade) was added to each vial to decompose the dried worm tissue. The samples were allowed to cold digest for 24 hr and then inserted into a thermostatically controlled (maintained at 50° C) graphite heating block and heated cautiously for several days. During the heating period an additional 1 ml of nitric acid was added to the samples. Two millilitres of 30-percent hydrogen peroxide was added to the samples after the volume of the acid was reduced to approximately 0.2 ml. The peroxide was added cautiously in 100- μl aliquots until the first millilitre was added. The second millilitre of peroxide was added after the oxidation reaction had subsided. The volume of the samples was again reduced to near dryness and the heating was discontinued. When the vials had attained room temperature, exactly 5 ml of 2N HNO_3 was added to each sample vial to reconstitute the precipitated salts. Each vial was capped and stored for later analysis.

Atomic absorption analysis

21. All flame atomization (FA) atomic absorption (AA) was conducted with a Perkin-Elmer Model 5000 atomic absorption spectrophotometer. All HGA atomic absorption determinations were conducted with Perkin-Elmer Model 500 or 2100 HGA units coupled to Perkin-Elmer Model 5000 or 603 atomic absorption instruments, respectively. The model 5000 AA was retrofitted with a Zeeman HGA background correction unit, and the model 603 was equipped with a deuterium arc background correction system. The model 500 HGA unit was equipped

with an auto injector Model AS-40, and the 2100 HGA unit was equipped with an auto injector model AS-1. Flame atomization absorbances and transient HGA-AA signals were recorded with Perkin-Elmer strip chart recorders (Model 56) and also sent automatically to Perkin-Elmer Model 3600 data station micro-computers. Software supplied with the data stations reduced the transient signals to a peak height and peak area for each element determined. This software was modified to print and store on disk the calculated area and peak height for a given AA signal. A second program was written to calculate standard curves, which were used to determine the concentrations of unknown samples. The polynomial regression algorithms used to calculate the standard curves are described by Rugg and Feldman (1980).

22. The instrument setup conditions for the FA-AA and HGA-AA determinations are similar to those described in USEPA (1979) and are also similar to those found in the manufacturers' reference manuals. The AA instruments were calibrated each time samples were analyzed for a given element. Instrument calibrations were generally checked after every five samples had been atomized into the flame unit, or injected into the HGA units.

23. Whole water samples determined for iron were analyzed by direct injection into the HGA units (Ediger, Peterson, and Kerber 1974; Sturgeon et al. 1979; Slavin 1980). Other than adding an additional 100 μ l of concentrated HNO_3 to 1-ml subsamples of the original acidified (pH 2-3) whole water seawater samples, no chemical separation techniques were utilized to concentrate these elements from the seawater matrix. The large, nonatomic background signal generated during the atomization of sea salt was eliminated by the use of the AA Model 5000 Zeeman background correction system (Fernandez, Meyers, and Slavin 1980; Fernandez and Giddings 1982). It was necessary to matrix match the unknown samples with the standards since chemical interferences are not corrected by the Zeeman effect. Therefore, all standards were prepared in trace metal stripped seawater and acidified in the same manner as the samples. The trace-metal-free seawater was prepared by the methods of Davey et al. (1970). Only iron could be determined routinely by the direct injection of the seawater samples. The concentrations of the other elements studied were at or below their respective detection limits. Metals (copper and cadmium) chemically separated and concentrated from the seawater samples with the

Co-APDC* coprecipitation technique were determined with the model 603 AA and the 2100 HGA unit. It was not necessary to background correct these separated samples during sample atomization. However, the samples and standards were matched. The standards were made up in a matrix solution consisting of Co-APDC obtained from extraction of blank seawater in an identical fashion as the unknown samples.

* Ammonium pyrrolidine dithiocarbamate.

APPENDIX C: CHEMICAL FORMULAS AND FIELD MUSSEL RESIDUE
CONCENTRATIONS AND WORM RESIDUE CONCENTRATIONS

Table C1
Chemical Contaminants Selected for Measurement
in Both Field and Laboratory Studies

Chlorinated hydrocarbon pesticides

Polychlorinated biphenyls
 Ethylan

Aromatic hydrocarbons \geq molecular weight 166

<u>Compound Class</u>	<u>Molecular Weight</u>
Fluorene	166
C-1* Fluorene	180
C-2* Fluorene	194
C-3* Fluorene	208
C-4* Fluorene	222
Phenanthrene	178
Anthracene	178
C-1* Phenanthrene/anthracene	192
C-2* Phenanthrene/anthracene	206
C-3* Phenanthrene/anthracene	220
C-4* Phenanthrene/anthracene	234
Fluoranthene	202
Pyrene	202
C-1* Fluoranthene/pyrene	216
C-2* Fluoranthene/pyrene	230
C-3* Fluoranthene/pyrene	244
C-4* Fluoranthene/pyrene	258
Benzanthracene/chrysene**	228
C-1* Benzanthracene/chrysene**	242
C-2* Benzanthracene/chrysene**	256
C-3* Benzanthracene/chrysene**	270
C-4* Benzanthracene/chrysene**	284
Benzofluoranthenes	252
Benzo(e)pyrene	252
Benzo(a)pyrene	252
Perylene	252

(Continued)

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table C1 (Concluded)

Compound Class	Molecular Weight
C-1* Benzopyrene/perylene**	266
C-2* Benzopyrene/perylene**	280
C-3* Benzopyrene/perylene**	294
C-4* Benzopyrene/perylene**	308
Benzoperylene**	376
Dibenzanthracene**	278
Coronene	300
Dibenzocrysene**	302
Hetrocyclic aromatic compounds	
Dibenzothiophene	184
C-1* Dibenzothiophene	198
C-2* Dibenzothiophene	212
C-3* Dibenzothiophene	226
C-4* Dibenzothiophene	240
Metals	
Cadmium	
Copper	
Chromium	
Iron	
Lead	
Manganese	
Nickel	
Zinc	

* C-1, C-2, C-3, and C-4 refer to the number of methyl groups substituted somewhere in the parent compound.

** These names are representative of the class of polynuclear aromatic hydrocarbons (PAHs) measured at each molecular weight.

Table C2

Complete Formulae for Calculating all SUM and CENT Variables

$$\begin{aligned}
 \text{PSUM} &= \text{POS166} + \text{POS178} + \text{POS202} + \text{POS228} + \text{POS252} + \text{POS276} + \text{POS278} + \\
 &\quad \text{POS300} + \text{POS302} \\
 \text{HSUM} &= \text{H1C166} + \text{H2C166} + \text{H3C166} + \text{H4C166} + \text{H1C178} + \text{H2C178} + \text{H3C178} + \\
 &\quad \text{H4C178} + \text{H1C202} + \text{H2C202} + \text{H3C202} + \text{H4C202} + \text{H1C228} + \text{H2C228} + \\
 &\quad \text{H3C228} + \text{H4C228} + \text{H1C252} + \text{H2C252} + \text{H3C252} + \text{H4C252} \\
 \text{SUM} &= \text{POS166} + \text{H1C166} + \text{H2C166} + \text{H3C166} + \text{H4C166} + \text{POS178} + \text{H1C178} + \\
 &\quad \text{H2C178} + \text{H3C178} + \text{H4C178} + \text{POS202} + \text{H1C202} + \text{H2C202} + \text{H3C202} + \\
 &\quad \text{H4C202} + \text{POS228} + \text{H1C228} + \text{H2C228} + \text{H3C228} + \text{H4C228} + \text{POS252} + \\
 &\quad \text{H1C252} + \text{H2C252} + \text{H3C252} + \text{H4C252} + \text{POS276} + \text{POS278} + \text{POS300} + \\
 &\quad \text{POS302} \\
 \text{PCENT} &= [\text{POS166} \cdot 166 + \text{POS178} \cdot 178 + \text{POS202} \cdot 202 + \text{POS228} \cdot 228 + \text{POS252} \cdot 252 + \\
 &\quad \text{POS276} \cdot 276 + \text{POS278} \cdot 278 + \text{POS300} \cdot 300 + \text{POS302} \cdot 302] / \text{PSUM} \\
 \text{HCENT} &= [\text{H1C166} \cdot 180 + \text{H2C166} \cdot 194 + \text{H3C166} \cdot 208 + \text{H4C166} \cdot 222 + \text{H1C178} \cdot 192 + \\
 &\quad \text{H2C178} \cdot 206 + \text{H3C178} \cdot 220 + \text{H4C178} \cdot 234 + \text{H1C202} \cdot 216 + \text{H2C202} \cdot 230 + \\
 &\quad \text{H3C202} \cdot 244 + \text{H4C202} \cdot 258 + \text{H1C228} \cdot 242 + \text{H2C228} \cdot 256 + \text{H3C228} \cdot 270 + \\
 &\quad \text{H4C228} \cdot 284 + \text{H1C252} \cdot 266 + \text{H2C252} \cdot 280 + \text{H3C252} \cdot 294 + \text{H4C252} \cdot 308] / \\
 &\quad \text{HSUM} \\
 \text{CENT} &= [\text{POS166} \cdot 166 + \text{H1C166} \cdot 180 + \text{H2C166} \cdot 194 + \text{H3C166} \cdot 208 + \text{H4C166} \cdot 222 + \\
 &\quad \text{POS178} \cdot 178 + \text{H1C178} \cdot 192 + \text{H2C178} \cdot 206 + \text{H3C178} \cdot 220 + \text{H4C178} \cdot 234 + \\
 &\quad \text{POS202} \cdot 202 + \text{H1C202} \cdot 216 + \text{H2C202} \cdot 230 + \text{H3C202} \cdot 244 + \text{H4C202} \cdot 258 + \\
 &\quad \text{POS228} \cdot 228 + \text{H1C228} \cdot 242 + \text{H2C228} \cdot 256 + \text{H3C228} \cdot 270 + \text{H4C228} \cdot 284 + \\
 &\quad \text{POS252} \cdot 252 + \text{H1C252} \cdot 266 + \text{H2C252} \cdot 280 + \text{H3C252} \cdot 294 + \text{H4C252} \cdot 308 + \\
 &\quad \text{POS276} \cdot 276 + \text{POS278} \cdot 278 + \text{POS300} \cdot 300 + \text{POS302} \cdot 302] / \text{SUM}
 \end{aligned}$$

The sum of alkyl homologs of PAH molecular weight 178 (HOS178) is calculated according to the following formula:

$$\text{HOS178} = \text{H1C178} + \text{H2C178} + \text{H3C178} + \text{H4C178}$$

where

$$\text{HOS178} = \text{sum of C-1 to C-4 alkyl-substituted 178 PAHs}$$

This statistic was chosen to describe the alkyl homologs because the 178 alkyl homologs are the most intense homologs within the Black Rock Harbor (BRH) PAH distribution and because they afford the greatest BRH to REFS concentration ratio. Alkyl homologs were included because of potential differences between them and parent PAHs.

Table C3

Tissue Residue Concentrations in *M. edulis* from the
T - 4 Field Collection in CLIS (22 Apr 83)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	210.0	117.0	98.0	38.0
Sum of 178 alkyl homologs	580.0	310.0	310.0	290.0
Fluoranthene	161.0	102.0	90.0	82.0
Benzo(a)pyrene	37.0	20.0	34.0	25.0
Ethylan	5.0	3.0	5.0	10.0
PCB as A1254	380.0	270.0	400.0	440.0
SUM of PAHs	2,600.0	1,520.0	1,650.0	1,380.0
CENTROID of PAHs	218.0	219.0	225.0	228.0
Copper	13.5	15.1	14.5	12.5
Cadmium	1.9	1.8	1.8	1.8
Chromium	1.8	3.8	2.2	1.6
Iron	370.0	1,400.0	530.0	340.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C4
Tissue Residue Concentrations in *M. edulis* from the
T + 0 Field Collection in CLIS (24 May 83)*

<u>Chemical Compound**</u>	<u>Station</u>	
	<u>1000E</u>	<u>REFS</u>
Phenanthrene	43.0	16.0
Sum of 178 alkyl homologs	1,440.0	290.0
Fluoranthene	161.0	52.0
Benzo(a)pyrene	100.0	18.0
Ethylan	102.0	9.0
PCB as A1254	1,080.0	500.0
SUM of PAHs	5,400.0	1,290.0
CENTROID of PAHs	230.0	232.0
Copper	16.5	10.9
Cadmium	2.0	2.3
Chromium	2.6	1.5
Iron	420.0	330.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID. The CNTR station was not deployed because of the dumping operation, and the 400E station was lost.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C5

Tissue Residue Concentrations in *M. edulis* from the
T + 2 Field Collection in CLIS (07 June 83)*

Chemical Compound**	Station		
	400E	1000E	REFS
Phenanthrene	69.0	41.0	13.0
Sum of 178 alkyl homologs	1,900.0	970.0	540.0
Fluoranthene	290.0	126.0	72.0
Benzo(a)pyrene	210.0	118.0	51.0
Ethylan	71.0	39.0	17.0
PCB as A1254	1,440.0	1,020.0	630.0
SUM of PAHs	8,700.0	4,700.0	2,500.0
CENTROID of PAHs	232.0	234.0	233.0
Copper	16.9	15.6	10.8
Cadmium	2.3	2.3	1.9
Chromium	3.0	3.0	2.0
Iron	510.0	560.0	560.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID. The CNTR station was not deployed because of the disposal operation.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C6
Tissue Residue Concentrations in *M. edulis* from the
T + 8 Field Collection in CLIS (10 Jul 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	11.0	14.0	9.0	7.0
Sum of 178 alkyl homologs	350.0	340.0	193.0	105.0
Fluoranthene	45.0	46.0	31.0	23.0
Benzo(a)pyrene	40.0	50.0	18.0	20.0
Ethylan	22.0	20.0	7.0	1.0
PCB as A1254	700.0	740.0	620.0	480.0
SUM of PAHs	1,870.0	2,100.0	1,020.0	760.0
CENTROID of PAHs	234.0	236.0	231.0	240.0
Copper	10.1	9.6	11.5	4.4
Cadmium	1.9	2.0	1.3	0.9
Chromium	1.4	1.4	3.2	0.8
Iron	340.0	370.0	820.0	240.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C7
Tissue Residue Concentrations in *M. edulis* from the
T + 12 Field Collection in CLIS (10 Aug 83)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	17.0	10.0	9.0	8.0
Sum of 178 alkyl homologs	250.0	160.0	96.0	65.0
Fluoranthene	41.0	28.0	20.0	15.0
Benzo(a)pyrene	41.0	17.0	16.0	13.0
Ethylan	9.0	8.0	3.0	1.0
PCB as A1254	640.0	660.0	550.0	570.0
SUM of PAHs	1,600.0	940.0	710.0	530.0
CENTROID of PAHs	237.0	236.0	239.0	240.0
Copper	5.3	5.6	7.5	5.8
Cadmium	0.9	0.9	1.2	1.1
Chromium	1.0	0.7	1.6	0.7
Iron	164.0	167.0	450.0	177.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C8
Tissue Residue Concentrations in *M. edulis* from the
T + 15 Field Collection in CLIS (06 Sep 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	13.0	9.0	10.0	6.0
Sum of 178 alkyl homologs	370.0	230.0	210.0	43.0
Fluoranthene	57.0	38.0	33.0	14.0
Benzo(a)pyrene	53.0	45.0	28.0	7.0
Ethylan	10.0	6.0	4.0	1.0
PCB as A1254	870.0	630.0	640.0	550.0
SUM of PAHs	2,100.0	1,540.0	1,240.0	350.0
CENTROID of PAHs	236.0	239.0	237.0	238.0
Copper	7.7	6.0	8.0	5.8
Cadmium	1.0	1.1	1.1	0.9
Chromium	1.2	0.9	1.1	0.9
Iron	260.0	179.0	290.0	260.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C9
Tissue Residue Concentrations in *M. edulis* from the
T + 21 Field Collection in CLIS (18 Oct 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	12.0	11.0	11.0	10.0
Sum of 178 alkyl homologs	132.0	101.0	88.0	46.0
Fluoranthene	33.0	25.0	22.0	16.0
Benzo(a)pyrene	24.0	9.0	17.0	9.0
Ethylan	2.0	2.0	1.0	0.0
PCB as A1254	540.0	680.0	570.0	420.0
SUM of PAHs	1,000.0	670.0	700.0	400.0
CENTROID of PAHs	240.0	234.0	239.0	238.0
Copper	22.1	16.3	15.1	16.4
Cadmium	5.1	4.4	4.8	5.0
Chromium	2.3	2.6	2.2	2.2
Iron	440.0	540.0	420.0	480.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C10
Tissue Residue Concentrations in *M. edulis* from the
T + 27 Field Collection in CLIS (29 Nov 83)*

<u>Chemical Compound**</u>	<u>Station†</u>		<u>REFS</u>
	<u>400E</u>	<u>1000E</u>	
Phenanthrene	18.0	10.0	8.0
Sum of 178 alkyl homologs	230.0	117.0	86 .0
Fluoranthene	68.0	36.0	37.0
Benzo(a)pyrene	39.0	32.0	19.0
Ethylan	3.0	1.0	0.0
PCB as A1254	540.0	380.0	450.0
SUM of PAHs	1,820.0	1,150.0	860.0
CENTROID of PAHs	240.0	244.0	240.0
Copper	16.4	21.0	23.3
Cadmium	3.2	3.4	3.6
Chromium	2.5	3.6	3.3
Iron	570.0	920.0	920.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID. The CNTR station was missing at the time of collection.

** These are the 12 contaminant measurements used for calculating BRH exposure.

† The CNTR station was missing at the time of collection.

Table C11

Tissue Residue Concentrations in *M. edulis* from the
T + 43 Field Collection in CLIS (20 Mar 84)*

<u>Chemical Compound**</u>	<u>Station†</u>		
	<u>CNTR</u>	<u>400E</u>	<u>REFS</u>
Phenanthrene	16	18	17
Sum of 178 alkyl homologs	94	78	70
Fluoranthene	28	26	24
Benzo(a)pyrene	8	4	7
Ethylan	2	1	1
PCB as A1254	350	330	280
SUM of PAHs	510	460	450
CENTROID of PAHs	229	230	231

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, and molecular weight for the statistic CENTROID. Metals were not measured for these samples. The 1000E station was missing at the time of collection.

** Metals were not measured for these samples.

† The 1000E station was missing at the time of collection.

Table C12

Tissue Residue Concentrations in *M. edulis* from the
T + 55 Field Collection in CLIS (05 June 84)*

Chemical Compound**	Station†		REFS
	400E	1000E	
Phenanthrene	6	6	4
Sum of 178 alkyl homologs	89	91	54
Fluoranthene	25	31	18
Benzo(a)pyrene	6	7	6
Ethylan	0	1	0
PCB as A1254	540	490	550
SUM of PAHs	520	550	370
CENTROID of PAHs	234	235	236

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, and molecular weight for the statistic CENTROID. Metals were not measured in these samples. The CNTR station was missing at the time of collection.

** Metals were not measured in these samples.

† The CNTR station was missing at the time of collection.

Table C13

Tissue Residue Concentrations in *M. edulis* from the
T + 116 Field Collection in CLIS (13 Aug 85)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	3.0	6.0	3.0	3.0
Sum of 178 alkyl homologs	79.0	124.0	80.0	58.0
Fluoranthene	18.0	27.0	24.0	19.0
Benzo(a)pyrene	18.0	40.0	22.0	17.0
Ethylan	1.0	2.0	1.0	0.0
PCB as A1254	310.0	350.0	450.0	440.0
SUM of PAHs	700.0	1,270.0	810.0	620.0
CENTROID of PAHs	242.0	243.0	241.0	244.0
Copper	8.5	7.5	6.9	7.6
Cadmium	1.5	1.3	1.3	1.3
Chromium	1.2	1.1	0.9	0.9
Iron	290.0	260.0	220.0	220.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C14

Tissue Residue Concentrations in *N. incisa* from the T - 39 Weeks
Field Collection in CLIS (17 Aug 82)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	189	--	210
SUM of PAHs	--	--	--	--
CENTROID of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C15

Tissue Residue Concentrations in *N. incisa* from the T - 26 Weeks
Field Collection in CLIS (16 Oct 82)*

<u>Chemical Compound**</u>	<u>Station</u>			<u>REFS</u>
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	240	--	290
SUM of PAHs	--	--	--	--
CENTROID of PAHs	--	--	--	--
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C16

Tissue Residue Concentrations in *N. incisa* from the T - 13 Weeks
Field Collection in CLIS (16 Feb 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	5.6	--	4.0
Sum of 178 alkyl homologs	--	67.0	--	34.0
Fluoranthene	--	37.0	--	26.0
Benzo(a)pyrene	--	19.0	--	10.0
Ethylan	--	0.0	--	0.0
PCB as A1254	--	340.0	--	290.0
SUM of PAHs	--	780.0	--	530.0
CENTROID of PAHs	--	242.9	--	244.4
Copper	--	18.1	--	21.0
Cadmium	--	0.1	--	0.5
Chromium	--	1.3	--	1.9
Iron	--	570.0	--	770.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C17

Tissue Residue Concentrations in *N. incisa* from the T - 11 Weeks
Field Collection in CLIS (04 Mar 83)*

Chemical Compound**	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	--	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--	--
Fluoranthene	--	--	--	--	--
Benzo(a)pyrene	--	--	--	--	--
Ethylan	--	--	--	--	--
PCB as A1254	--	--	--	--	--
SUM of PAHs	--	--	--	--	--
CENTROID of PAHs	--	--	--	--	--
Copper	36.0	39.0	37.0	42.0	26.0
Cadmium	0.8	0.5	0.7	1.0	0.6
Chromium	2.9	1.7	1.7	2.4	2.0
Iron	980.0	790.0	760.0	980.0	1,040.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C18

Tissue Residue Concentrations in *N. incisa* from the T - 5 WeeksField Collection in CLIS (12 Mar 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	10.7	--	9.6
Sum of 178 alkyl homologs	0	79.0	0	50.0
Fluoranthene	--	47.0	--	35.0
Benzo(a)pyrene	--	24.0	--	21.0
Ethylan	--	0.0	--	0.0
PCB as A1254	--	390.0	--	340.0
SUM of PAHs	--	960.0	--	710.0
CENTROID of PAHs	--	241.4	--	243.7
Copper	--	49.0	--	28.0
Cadmium	--	0.5	--	0.6
Chromium	--	3.9	--	2.1
Iron	--	1,360.0	--	930.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C19

Tissue Residue Concentrations in *N. incisa* from the T + 2 WeeksField Collection in CLIS (02 Jun 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	360.0	60.0	6.2
Sum of 178 alkyl homologs	--	3,690.0	840.0	44.0
Fluoranthene	--	970.0	197.0	19.0
Benzo(a)pyrene	--	250.0	85.0	13.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,060.0	630.0	290.0
SUM of PAHs	--	15,100.0	4,200.0	420.0
CENTROID of PAHs	--	221.9	229.3	241.0
Copper	--	37.0	23.0	--
Cadmium	--	0.6	0.2	--
Chromium	--	1.1	1.2	--
Iron	--	670.0	680.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C20

Tissue Residue Concentrations in *N. incisa* from the T + 7 Weeks
Field Collection in CLIS (03 Jul 83)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	300.0	8.3	7.8
Sum of 178 alkyl homologs	--	3,700.0	260.0	79.0
Fluoranthene	--	650.0	49.0	31.0
Benzo(a)pyrene	--	420.0	66.0	19.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,160.0	630.0	290.0
SUM of PAHs	--	16,700.0	1,980.0	840.0
CENTROID of PAHs	--	229.5	241.4	243.3
Copper	--	--	--	--
Caesium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C21

Tissue Residue Concentrations in *N. incisa* from the T + 8 Weeks
Field Collection in CLIS (13 Jul 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
CENTROID of PAHs	--	--	--	--
Copper	--	27.0	37.0	--
Cadmium	--	0.3	0.5	--
Chromium	--	3.2	1.9	--
Iron	--	520.0	690.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C22

Tissue Residue Concentrations in *N. incisa* from the T + 16 Weeks
Field Collection in CLIS (06 Sep 83)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	14.3	9.8	7.3
Sum of 178 alkyl homologs	--	890.0	420.0	66.0
Fluoranthene	--	165.0	111.0	37.0
Benzo(a)pyrene	--	195.0	85.0	27.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	1,240.0	1,000.0	370.0
SUM of PAHs	--	5,900.0	2,900.0	850.0
CENTROID of PAHs	--	239.0	239.4	243.8
Copper	--	27.0	37.0	26.0
Cadmium	--	0.2	0.4	0.5
Chromium	--	1.8	2.3	2.2
Iron	--	650.0	970.0	1,210.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C23

Tissue Residue Concentrations in *N. incisa* from the T + 28 WeeksField Collection in CLIS (29 Nov 83)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	48.0	5.8	3.4
Sum of 178 alkyl homologs	--	870.0	93.0	34.0
Fluoranthene	--	210.0	36.0	23.0
Benzo(a)pyrene	--	122.0	35.0	16.0
Ethylan	--	0.0	0.0	0.0
PCB as A1254	--	690.0	480.0	240.0
SUM of PAHs	--	5,100.0	1,330.0	550.0
CENTROID of PAHs	--	232.7	249.4	248.4
Copper	--	40.0	17.8	--
Cadmium	--	0.4	0.2	--
Chromium	--	1.8	1.4	--
Iron	--	790.0	530.0	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C24

Tissue Residue Concentrations in *N. incisa* from the T + 44 WeeksField Collection in CLIS (20 Mar 84)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	220.0	4.4	4.6	1.5
Sum of 178 alkyl homologs	1,100.0	950.0	18.0	1.2
Fluoranthene	270.0	230.0	31.0	24.0
Benzo(a)pyrene	159.0	132.0	22.0	10.0
Ethylan	0.0	0.0	0.0	0.0
PCB as A1254	650.0	580.0	350.0	220.0
SUM of PAHs	4,900.0	4,300.0	380.0	183.0
CENTROID of PAHs	221.2	224.7	235.0	233.1
Copper	--	--	--	--
Cadmium	--	--	--	--
Chromium	--	--	--	--
Iron	--	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C25

Tissue Residue Concentrations in *N. incisa* from the T + 56 Weeks
Field Collection in CLIS (13 Jun 84)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
CENTROID of PAHs	--	--	--	--
Copper	174.0	--	44.0	39.0
Cadmium	1.0	--	0.6	0.7
Chromium	5.9	--	2.1	1.9
Iron	380.0	--	680.0	770.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C26

Tissue Residue Concentrations in *N. incisa* from the T + 73 WeeksField Collection in CLIS (10 Oct 84)*

<u>Chemical Compound**</u>	<u>Station</u>			
	<u>CNTR</u>	<u>400E</u>	<u>1000E</u>	<u>REFS</u>
Phenanthrene	--	--	--	--
Sum of 178 alkyl homologs	--	--	--	--
Fluoranthene	--	--	--	--
Benzo(a)pyrene	--	--	--	--
Ethylan	--	--	--	--
PCB as A1254	--	--	--	--
SUM of PAHs	--	--	--	--
CENTROID of PAHs	--	--	--	--
Copper	50.0	44.0	47.0	28.0
Cadmium	1.6	1.2	2.3	1.3
Chromium	3.3	1.0	1.6	1.6
Iron	790.0	840.0	930.0	610.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C27

Tissue Residue Concentrations in *N. incisa* from the T + 74 Weeks
Field Collection in CLIS (16 Oct 84)*

Chemical Compound**	Station			
	CNTR	400E	1000E	REFS
Phenanthrene	500.0	7.9	5.1	3.2
Sum of 178 alkyl homologs	4,800.0	200.0	124.0	33.0
Fluoranthene	1,410.0	96.0	57.0	27.0
Benzo(a)pyrene	102.0	40.0	46.0	19.0
Ethylan	13.6	0.0	0.0	0.0
PCB as A1254	710.0	510.0	350.0	300.0
SUM of PAHs	16,000.0	1,660.0	1,320.0	580.0
CENTROID of PAHs	208.1	233.9	242.5	246.3
Copper	86.0	--	--	--
Cadmium	0.6	--	--	--
Chromium	2.5	--	--	--
Iron	680.0	--	--	--

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C28

Tissue Residue Concentrations in *N. incisa* from the T + 140 Weeks
Field Collection in CLIS (24 Jan 86)*

Chemical Compound**	Station				
	CNTR	200E	400E	1000E	REFS
Phenanthrene	7.3	--	4.7	12.0	
Sum of 178 alkyl homologs	1,070.0	--	58.0	390.0	
Fluoranthene	300.0	--	23.0	78.0	27.0
Benzo(a)pyrene	162.0	--	21.0	91.0	23.0
Ethylan	6.2	--	0.0	0.0	0.0
PCB as Al254	900.0	--	310.0	300.0	160.0
SUM of PAHs	6,400.0	--	630.0	3,000.0	660.0
CENTROID of PAHs	232.1	--	244.0	244.5	253.7
Copper	83.0	53.0	44.0	46.0	32.0
Cadmium	1.8	0.9	0.6	0.8	0.7
Chromium	9.9	4.3	2.4	2.0	2.1
Iron	840.0	970.0	1,250.0	920.0	970.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C29

Tissue Residue Concentrations in *M. edulis* on Day 0 from the
First and Second Laboratory Experiments

<u>Chemical Compound**</u>	<u>Experiment One</u>	<u>Experiment Two</u>
Phenanthrene	38.00	63.00
Sum of 178 alkyl homologs	76.00	99.00
Fluoranthene	45.00	77.00
Benzo(a)pyrene	1.10	1.40
Ethylan	0.00	0.00
PCB as A1254	117.00	210.00
SUM of PAHs	300.00	410.00
CENTROID of PAHs	208.00	203.00
Copper	9.96	5.77
Cadmium	1.50	1.70
Chromium	4.30	2.10
Iron	160.0	190.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C30
Tissue Residue Concentrations in *M. edulis* on Day 14 from the
First Laboratory Experiment

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	50	100
Phenanthrene	19.0	35.0	95.0
Sum of 178 alkyl homologs	102.0	1,600.0	3,900.0
Fluoranthene	50.0	750.0	240.0
Benzo(a)pyrene	31.0	156.0	108.0
Ethylan	4.0	870.0	430.0
PCB as A1254	154.0	2,100.0	3,700.0
SUM of PAHs	950.0	13,000.0	6,100.0
CENTROID of PAHs	238.0	228.0	223.0
Copper	12.9	148.0	156.0
Cadmium	1.6	2.9	2.6
Chromium	11.0	13.0	18.0
Iron	670.0	350.0	570.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C31

Tissue Residue Concentrations in *M. edulis* on Day 7 of the
Second Laboratory Experiment

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	10	30
Phenanthrene	43.00	70.0	153.0
Sum of 178 alkyl homologs	139.00	1,900.0	3,800.0
Fluoranthene	84.00	350.0	630.0
Benzo(a)pyrene	17.00	45.0	78.0
Ethylan	0.00	300.0	510.0
PCB as A1254	280.00	1,100.0	2,100.0
SUM of PAHs	850.00	5,400.0	11,000.0
CENTROID of PAHs	225.00	218.0	217.0
Copper	8.99	72.0	89.9
Cadmium	1.70	1.8	1.9
Chromium	3.00	5.0	4.6
Iron	620.00	300.0	210.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C32
Tissue Residue Concentrations in *M. edulis* on Day 14 of the
Second Laboratory Experiment

<u>Chemical Compound**</u>	<u>Concentration at Indicated Percent BRH</u>		
	<u>0</u>	<u>10</u>	<u>30</u>
Phenanthrene	39.00	41.0	68.0
Sum of 178 alkyl homologs	200.00	2,200.0	2,900.0
Fluoranthene	102.00	450.0	520.0
Benzo(a)pyrene	25.00	64.0	88.0
Ethylan	3.30	680.0	680.0
PCB as A1254	270.00	1,900.0	3,600.0
SUM of PAHs	1,200.00	7,200.0	9,200.0
CENTROID of PAHs	225.00	222.0	221.0
Copper	7.83	109.0	116.0
Cadmium	1.40	1.7	2.1
Chromium	3.70	3.5	5.6
Iron	510.00	280.0	300.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C33
Tissue Residue Concentrations in *M. edulis* on Day 21 of the
Second Laboratory Experiment

<u>Chemical Compound**</u>	<u>Concentration at Indicated Percent BRH</u>		
	<u>0</u>	<u>10</u>	<u>30</u>
Phenanthrene	37.00	30.0	29.0
Sum of 178 alkyl homologs	220.00	2,300.0	2,400.0
Fluoranthene	91.00	330.0	320.0
Benzo(a)pyrene	21.00	67.0	86.0
Ethylan	4.70	700.0	660.0
PCB as A1254	360.00	1,700.0	3,600.0
SUM of PAHs	1,200.00	7,000.0	7,700.0
CENTROID of PAHs	226.00	223.0	224.0
Copper	7.55	85.7	174.0
Cadmium	1.60	1.9	2.3
Chromium	3.20	4.5	6.8
Iron	430.00	340.0	300.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C34

Tissue Residue Concentrations in *M. edulis* on Day 28 of the
Second Laboratory Experiment

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	10	30
Phenanthrene	21.0	27.0	23.0
Sum of 178 alkyl homologs	127.0	2,100.0	2,400.0
Fluoranthene	59.0	330.0	350.0
Benzo(a)pyrene	12.0	57.0	76.0
Ethylan	3.0	730.0	770.0
PCB as A1254	280.0	1,800.0	3,700.0
SUM of PAHs	780.0	6,600.0	7,900.0
CENTROID of PAHs	226.0	221.0	224.0
Copper	10.1	69.9	134.0
Cadmium	1.4	2.2	2.1
Chromium	5.6	3.1	5.8
Iron	360.0	300.0	260.0

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C35

Tissue Residue Concentrations in *N. incisa* from Day 0
Laboratory Experiment - Bedded Sediment Exposure

<u>Chemical Compound**</u>	<u>Concentration*</u>
Phenanthrene	26.50
Sum of 178 alkyl homologs	32.00
Fluoranthene	13.60
Benzo(a)pyrene	12.40
Ethylan	0.00
PCB as A1254	134.00
SUM of PAHs	407.00
CENTROID of PAHs	235.00
Copper	44.50
Cadmium	0.71
Chromium	12.20
Iron	1,510.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C36

Tissue Residue Concentrations in *N. incisa* from Day 10Laboratory Experiment - Bedded Sediment Exposure

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	10	30
Phenanthrene	11.500	313.00	754.00
Sum of 178 alkyl homologs	50.500	1,700.00	4,340.00
Fluoranthene	20.600	382.00	1,010.00
Benzo(a)pyrene	13.200	33.20	58.40
Ethylan	0.000	23.60	112.00
PCB as A1254	197.000	536.00	977.00
SUM of PAHs	493.000	5,020.00	12,500.00
CENTROID of PAHs	237.000	210.00	208.00
Copper	36.400	39.50	40.00
Cadmium	0.710	0.74	0.73
Chromium	8.310	6.13	8.44
Iron	893.000	856.00	936.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C37

Tissue Residue Concentrations in *N. incisa* from Day 21Laboratory Experiment - Bedded Sediment Exposure

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	10	30
Phenanthrene	7.58	206.00	339.00
Sum of 178 alkyl homologs	--	1,710.00	3,670.00
Fluoranthene	19.20	344.00	692.00
Benzo(a)pyrene	10.60	58.60	102.00
Ethylan	0.00	70.90	46.90
PCB as A1254	187.00	701.00	956.00
SUM of PAHs	--	5,420.00	10,900.00
CENTROID of PAHs	--	216.00	216.00
Copper	41.30	43.90	59.00
Cadmium	0.80	0.89	0.69
Chromium	55.30	1.03	55.80
Iron	1,790.00	1,563.00	1,650.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C38

Tissue Residue Concentrations in *N. incisa* from Day 28Laboratory Experiment - Bedded Sediment Exposure

<u>Chemical Compound**</u>	<u>Concentration at Indicated Percent BRH</u>		
	<u>0</u>	<u>10</u>	<u>30</u>
Phenanthrene	5.73	79.50	234.00
Sum of 178 alkyl homologs	--	1,270.00	2,370.00
Fluoranthene	16.20	247.00	442.00
Benzo(a)pyrene	7.77	60.60	74.50
Ethylan	0.00	27.70	49.00
PCB as A1254	140.00	556.00	655.00
SUM of PAHs	--	4,140.00	7,290.00
CENTROID of PAHs	--	219.00	216.00
Copper	31.60	41.80	55.40
Cadmium	0.77	0.72	0.72
Chromium	3.39	15.00	6.23
Iron	805.00	975.00	955.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C39

Tissue Residue Concentrations in *N. incisa* from Day 55
Laboratory Experiment - Bedded Sediment Exposure

<u>Chemical Compound**</u>	<u>Concentration at Indicated Percent BRH</u>		
	<u>0</u>	<u>10</u>	<u>30</u>
Phenanthrene	--	231.00	224.00
Sum of 178 alkyl homologs	--	1,740.00	3,330.00
Fluoranthene	17.80	302.00	528.00
Benzo(a)pyrene	7.61	80.70	130.00
Ethylan	0.00	47.80	93.00
PCB as A1254	236.00	1,460.00	2,360.00
SUM of PAHs	--	5,850.00	10,170.00
CENTROID of PAHs	--	217.00	217.00
Copper	36.40	34.70	48.2
Cadmium	0.74	0.68	0.53
Chromium	7.47	5.76	3.28
Iron	879.00	980.00	1,070.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C40
Tissue Residue Concentrations in *N. incisa* from Day 0
Laboratory Experiment - Bedded Sediment Exposure

<u>Chemical Compound**</u>	<u>Concentration*</u>
Phenanthrene	3.75
Sum of 178 alkyl homologs	47.70
Fluoranthene	17.00
Benzo(a)pyrene	5.67
Ethylan	0.00
PCB as A1254	183.00
SUM of PAHs	238.00
CENTROID of PAHs	229.00
Copper	31.80
Cadmium	0.53
Chromium	53.70
Iron	1,100.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.

Table C41

Tissue Residue Concentrations in *N. incisa* from Day 28Laboratory Experiment - Bedded Sediment Exposure

Chemical Compound**	Concentration at Indicated Percent BRH		
	0	50	100
Phenanthrene	4.17	7.90	14.70
Sum of 178 alkyl homologs	124.00	623.00	1,500.00
Fluoranthene	38.80	140.00	264.00
Benzo(a)pyrene	10.20	35.80	96.50
Ethylan	0.00	8.61	84.10
PCB as A1254	276.00	1,070.00	1,160.00
SUM of PAHs	611.00	2,440.00	5,700.00
CENTROID of PAHs	227.00	223.00	224.00
Copper	44.10	325.00	636.00
Cadmium	0.69	1.04	1.45
Chromium	43.50	29.50	50.8
Iron	1,180.00	1,120.00	1,070.00

* Units are nanograms per gram dry weight for the organic compounds and the statistic SUM, micrograms per gram dry weight for the inorganic elements, and molecular weight for the statistic CENTROID.

** These are the 12 contaminant measurements used for calculating BRH exposure.